KANSAS STATE AGRICULTURAL COLLEGE
MAY 14 1923
LIBRARY

ECONOMIC GEOLOGY

VOL. XVIII. APRIL–MAY, 1923. NO. 3

THE GEOLOGY OF THE HOMESTAKE MINE.[1]

SIDNEY PAIGE.

INTRODUCTION.

My interest in the nature and origin of the Homestake ore body of South Dakota, while naturally latent at the inception of my work in the pre-Cambrian rocks of the Black Hills, became suddenly acute when structural studies in the vicinity of the mine suggested that the deposit was unusual and actually very different from the published descriptions of it.[2] An added glamour is attached to the mine, perhaps, because strict censorship had prevailed for many years over all information concerning it.

The consent of T. J. Grier, therefore, at my earnest solicitation, in 1912, to a brief examination of the mine workings, to be limited to three days, was regarded as a windfall and I eagerly took advantage of it. A brief paper presented before the Geological Society of America resulted.[3] My interest in the mine was increased by this brief examination, which also resulted in a determination to continue it some day. This opportunity was afforded in 1920 when permission was again requested to study the mine,

[1] Published with the permission of the Director of the U. S. Geological Survey. Presented to the Society of Economic Geologists, Ann Arbor Meeting, December, 1922.

[2] Iriving, J. D., and others, "Economic Resources of the Northern Black Hills," Prof. Paper 26, U. S. Geol. Survey, 1904.

[3] Paige, Sidney, "Pre-Cambrian Structure of the Northern Black Hills, South Dakota, and its Bearing on the Origin of the Homestake Ore Body," *Bull. Geol. Soc. Amer.*, vol. 24, pp. 293–300, 1913.

it being agreed that studies were to be directed solely toward investigating the nature and origin of the ore body.[4] This permission was granted by Mr. B. C. Yates. Just prior to this time two geologists had been employed by the company—Mr. L. B. Wright and Mr. J. O. Hosted. They had about completed the mapping of the Tertiary porphyry intrusives at the initiation of our work and for six weeks we studied the mine together. Their knowledge of the workings and willingness to assist me in every way is hereby gratefully acknowledged.

The six weeks' underground work served to establish firmly most of the ideas formulated in my earlier paper. As a result of this work I prepared in Washington generalized geologic maps of 10 levels, and during the summer of 1922 returned to the mine to check them against recent developments. During these two years, following lines laid down in our previous studies, Wright and Hosted completed very detailed maps, and with these in hand certain errors unavoidable in a six weeks' study were corrected on my generalized maps. It is with pleasure that I attach their names as collaborators both to the surface geologic map and to the maps of the mine levels.

BROAD GEOLOGIC RELATIONS.[5]

The Homestake mine is at Lead, in the northern Black Hills of South Dakota. The Black Hills owe their existence to the dissection of a great oval domical uplift. A central core of pre-Cambrian rock is flanked on all sides by Paleozoic and younger rocks. At the north, porphyries of Tertiary age break through schists and Paleozoic rocks and dome the latter at many places; sills and laccoliths are characteristically developed.

The significant facts of the general geology that have a bearing on the origin of the Homestake mine are few in number and easily stated. The great bulk of the pre-Cambrian schists are

[4] The present paper is a result of this study which is to be published as a bulletin of the U. S. Geological Survey entitled: "The Geology of the Vicinity of Lead, South Dakota, and its Bearing on the Homestake Ore Body."

[5] Black Hills Folio, N. H. Darton and Sidney Paige (in press).

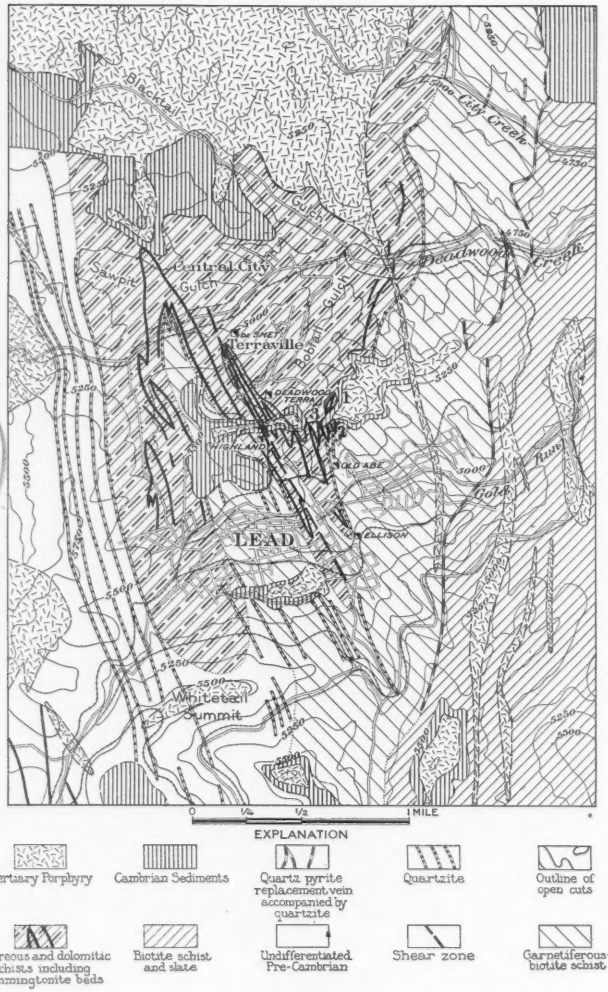
of sedimentary origin; they are closely folded and metamorphosed and during pre-Cambrian time were invaded first by considerable masses of dioritic rocks (now amphibolites) and later by large masses of coarse granite. The granites are conceived of as having come to place at a late stage of the metamorphic cycle and to have contributed toward it in no small degree. Lit-par-lit injection, compression of the surrounding sediments, the injection of countless pegmatite dikes and veins (both mineralized) were all facies of this process.

The original sediments from which the schists were derived comprised all the normal sedimentary rocks and some in which unusual amounts of iron accumulated. Of all these sediments the most important, economically, are the carbonate rocks—rocks made up of varying proportions of calcium, magnesium, and iron carbonate. These have turned out to be more abundant than was recognized by earlier workers (in fact, they were not recognized) and prove to be very significant when the origin of the Homestake mine is considered.

Details of structure in the pre-Cambrian rocks of the Black Hills as a whole need not be described. It is sufficient to state that the broader structures were deciphered, and that there exist a series of great anticlines and synclines, on which countless minor folds are imposed. Dips are prevailingly steep and to the east (the folds are generally overturned) and the strike is prevailingly northwest, although variations from this strike and dip do occur. Viewed broadly, the schistosity in many places accords with the bedding.

GEOLOGY IN THE VICINITY OF LEAD.

The pre-Cambrian schists around Lead may, for convenience, be divided into three larger groups and a number of minor beds within the groups. (See Fig. 34.) Highest stratigraphically in the series, and to the east, are biotite slates and schists, rocks characteristically argillaceous or siliceous. Beneath these are rocks very similar in composition, but characterized by more abundant garnet. Separating the two groups is a thin quartzite



STATE AGRICULTURAL COLLEGE
MAY 14 1923
LIBRARY

FIG. 34. Geologic map of the vicinity of Lead, South Dakota.

accompanied by graphitic slate, pyrite, and much secondary quartz—locally termed "the iron dike." This bed weathers to a siliceous limonitic gossan and is useful in deciphering structure, for it can be traced a long distance.

Beneath the garnetiferous schists occur a considerable thickness of schists characterized by notable amounts of carbonate. They are separated, however, from the overlying garnetiferous schists by a zone of thin quartzite and slate. These latter rocks, because of their generally prominent outcrop, can be followed across country, and thus are of great use in deciphering structure. The quartzites of this zone are in places pulled apart and squeezed, and are therefore not perfectly continuous in their outcrop, but their usefulness is nevertheless great. They are in more or less constant proximity to and overlie the ore in the mine. In fact, they mark an upper boundary, stratigraphically above which ore is not found.

The carbonate series includes many varieties of schist in which, in addition to varying amounts of iron, magnesium, and calcium carbonate, there occur biotite mica, sericite mica, phlogopite (Green mica), chlorite, amphibole, garnet, quartz, and varying amounts of sulphides and gold.

These rocks are well exposed in the railroad cut opposite the mouth of Blacktail Gulch, on Deadwood Creek. Here a fairly pure band of the calcareous rock outcrops, and there are many places in the small gulch on which Terraville is built (Bobtail Gulch), as well as in Deadwood Gulch in the vicinity of Central, where the calcareous beds, more or less impure, may be observed.

A highly metamorphic bed which outcrops in Deadwood Creek a short distance below the mouth of Blacktail Gulch, and which can be traced, with interruptions, to the Homestake open cut and thence into the mine, is peculiar in that it contains many small flattened lenses and bands of sugar-grained quartz set in a compact matrix of amphibole and garnet. This rock is the principal ore bearer of the Homestake lode system. The amphibole proves to be cummingtonite, the iron-magnesium amphibole, and the garnet is a lime-iron-aluminum garnet. The development of

these silicates suggests at once that the bed may be the metamorphic equivalent of a sideritic dolomite and that the quartz may represent residual chert. This proves to be the case, as will be shown below. A second bed similar to this occurs a short distance lower stratigraphically, but can not be traced so far, though in the upper workings of the mine and on some lower levels there are certainly more than one of these beds.

Another variety of the calcareous schist is characterized by chlorite and biotite. This rock exhibits various shades of green and has in places a decidedly micaceous appearance and a moderately well-developed cleavage. It has little resemblance to limestone, though it may carry as high as 50 per cent. of carbonate. A variety noted at a number of places in the northern hills is light grayish-green and is spotted with red iron oxide. It is a schistose rock composed of quartz and chlorite, throughout which are patches of ferriferous dolomitic carbonate. The oxidation of the iron-bearing carbonate causes the spotted appearance. In the microphotograph the black areas represent this oxidized ferriferous carbonate, the chlorite is gray, and the quartz white. There is no possibility of this carbonate being secondary in origin. It is an integral part of the original rock.

PETROGRAPHIC DETAILS OF CARBONATE ROCKS.

As remarked earlier, and as may be plainly seen by consulting the map (Fig. 34), the strike of this carbonate series carries them directly into the great open cut of the Homestake mine, and below under "Structure," and in the descriptions of the ore bodies, their relations to the ore will be pointed out. Abundant specimens of ore and wall rock were collected and examined with a microscope and a number were analyzed to prove that the series involved in the ore zone was this carbonate series. A description of a few of these types of rocks follows:

At the extreme north end of the ore body, on the surface, in the De Smet open cut, a remnant of ore remained undisturbed in the trough of a minor synclinal fold. This rock is dark green

to black in color and rather massive and micaceous. With the microscope abundant carbonate can be seen, which on analysis proves to be magnesian and iron carbonate. Lime, magnesia, iron, and carbon dioxide were determined as follows: Acid soluble—CaO 0.0; MgO 2.6; Fe_2O_3 23.9; CO_2 7.2, from which the percentage composition of carbonates was calculated, thus—$CaCO_3$ 0.0; $MgCO_3$ 5.4; $FeCO_3$ 11.6; Fe_2O_3 16.0 (as limonite). Manganese carbonate is not present.

This carbonate is abundant and in the illustrations appears as cloudy patches (see Fig. 35), set in a groundmass of quartz and

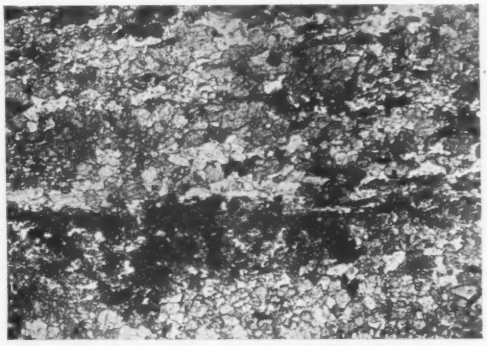


FIG. 35. Dolomitic iron bearing carbonate rock from the 300-foot level at B and M Shaft.

green mica. The border of many of the carbonate patches has altered to a brownish-red mineral (limonite ?). There is no doubt that this carbonate is an integral and original part of the rock, and that this rock was, before metamorphism, a dolomitic or sideritic sandstone.

It should be borne in mind that this is the ore-carrier of the De Smet ore body of the Homestake mine.

On the 300-foot level at the B and M (Old Abe) Shaft a bluish banded calcareous schist is made up dominantly of carbonate (see Fig. 35) with abundant chlorite, some mica, some amphibole, and subsidiary quartz.

An analysis shows the following percentage composition of carbonate: $CaCO_3$ 5.5; $MgCO_3$ 9.6; $FeCO_3$ 4.7; Fe_2O_3 28.3 (as limonite).

Here, as in many other specimens to be described, it is clear that the mica and amphibole replace carbonate. This rock was originally a dolomitic, iron-bearing, carbonate rock. Another specimen, collected at the edge of the ore body on the 300-foot level, is a siliceous schist, but contains layers of carbonate.

Typifying the more highly metamorphic examples of these carbonate rocks is the "80-foot" ledge on the 400 level. This stratum is west of the main ore body and west of the footwall shear zone, but is typical of the highly metamorphic strata found also east of the shear zone. Here there is an abundant development of cummingtonite and green mica, enmeshed in a groundmass of quartz and a subsidiary feldspar. *Residual carbonate* is seen with the microscope, and Fig. 36 illustrates clearly the characteristic fan-shaped development of cummingtonite, the iron

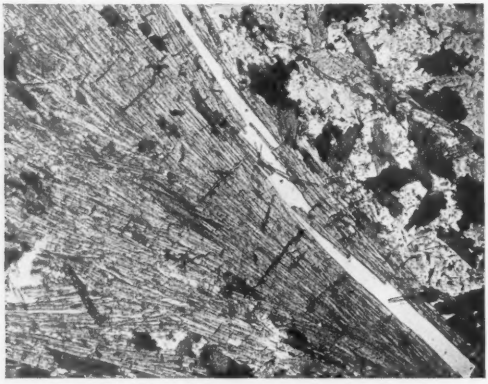


FIG. 36. Highly Metamorphic Carbonate rock from the 400-foot level, west of main shear zone.

magnesia amphibole. It is significant that the carbonates in places proves to be quite free of calcium as is this silicate.

Another specimen from the small Independence ledge on this level (300) illustrates the growth of cummingtonite even more clearly than the previous specimen. At this locality the Independence ledge plunges southeastward as if forming the nose of an anticlinal fold. The specimen was collected near the western wall. Fig. 37 shows the rather scant patches of carbonate inter-

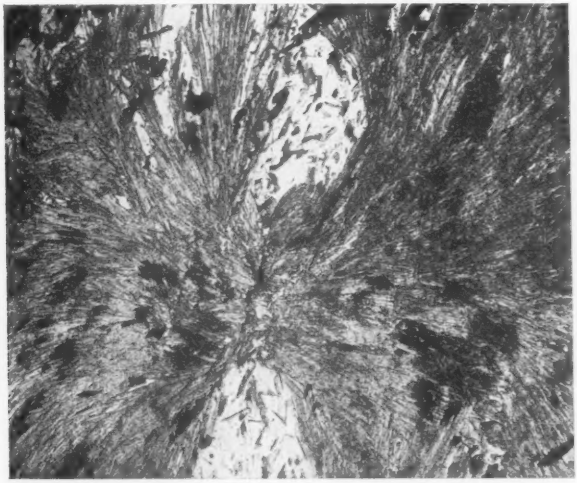


FIG. 37. Cummingtonite rock from Independence Ledge.

spersed with the quartz between blades of cummingtonite. Inasmuch as at other localities the cummingtonite may be seen as bands in carbonate-bearing schists, there is no reason to doubt that this almost complete replacement is simply a matter of degree. The cummingtonite not only has replaced the carbonate, but also much quartz.

Examples such as the above can be multiplied, but space does not permit of their presentation here. The results of other partial analyses of carbonate rocks from or near the various ore bodies and the examination of numerous thin sections of the rock clearly prove that abundant carbonate is present as an integral part of the ore-bearing series.

CHEMICAL ANALYSES OF ROCKS, MINERALS, AND MINE WATERS.

W. J. Sharwood has published[6] a number of analyses of rocks, and rock-making minerals, and mine waters from the Homestake mine. The results may be epitomized as follows:

In seven analyses of slates, all but one of which are regarded as wall rocks, the lime and magnesia is notably low. Referring to one of a number of analyses of chlorites, Sharwood adds that No. 42 was associated with magnesian siderite in a specimen that was called "massive ore" by Irving. I have no doubt that one of the carbonate rocks is here indicated as chlorite and is a normal metamorphism derivative of such a rock, and the observation is in entire agreement with my own. To Sharwood belongs the credit of first recognizing cummingtonite, the iron-magnesium amphibole. He presents a number of analyses of this mineral, described by Irving and Emmons as tremolite. Of the carbonates that he analyzed a number clearly are no more nor less than one of the gangue minerals in the normal sulphide ore. Many analyses of mine water were made by Sharwood. Sharwood says[7] "analyses of water from the mine under normal conditions, as compared with water from other sources in the vicinity, show a considerably larger proportion of lime and magnesia. During the fire period this condition is even more accentuated." It is clear that these facts lend support to prove that notable amounts of carbonate rock are in the mine workings.

STRUCTURE.

As stated earlier, the pre-Cambrian rocks of the Black Hills comprise (1) a great thickness of metamorphosed sedimentary rocks; (2) basic igneous rocks which invaded these, prior to metamorphism, and which in consequence are metamorphosed to amphibolites; and (3) granite which invades alike the metamorphic, sedimentary, and igneous rocks.

[6] Sharwood, W. J., "Analyses of Some Rocks and Minerals from the Homestake Mine, South Dakota," ECON. GEOL., vol. 6, No. 8, Dec., 1911.

[7] *Op. cit.*, p. 738.

The Homestake ore bodies occur entirely within the metamorphosed sedimentary rocks and the idea, as has been shown by field and laboratory observation, that any pre-Cambrian igneous rocks are involved in their structure can be dismissed. Although metamorphosed basic dikes do occur in the general vicinity of the mine, no pre-Cambrian dikes were observed in the mine, and none of the ore-bearing ledges (so called) are composed of such rocks. Granite, likewise, does not occur in the mine, though much quartz in veinlets and masses has been introduced into the rocks, and is, no doubt, an end product of the cooling underlying granite.

To explain the structure of the Homestake ore bodies, therefore, one must rely wholly on those principles which govern the metamorphism, folding, faulting, and mineralization of a series of sedimentary rocks.

A study of the field relations here and in other regions proves conclusively that where rocks are highly compressed under conditions of deep burial, a system of folds is evolved which have certain very well-known characteristics, viz., the major folds carry secondary folds upon their flanks, the secondary folds carry a tertiary system, the third system carries a fourth, etc. In their large and in their minor characteristics, also, all these folds bear important resemblances. They are generally thicker at their crests and troughs than along their flanks. They develop cleavage across the bedding of the strata at the turns of the folds nearly at right angles to the axial plane of the fold. Soft beds are more prone to fold than hard beds—hard beds may rupture and be pulled apart for long distances. All of these features may be studied on the small folds, some of them may be observed on the intermediate folds, and others may be inferred with respect to the major folds after field study.

To decipher the intricacies of the folds near Lead it was necessary to trace on the surface a number of definite beds and to follow the folds of these beds underground in the mine. Although the pre-Cambrian rocks are invaded by Tertiary porphyry and Cambrian cover conceals their outcrops in places, it proved

possible to establish the position of the major and of many of the minor folds.

The axis of a major anticline passes southward through Central City and swings southeastward near Lead. (See Fig. 34.) West of this major anticline is a major syncline with a southeasterly trending axis. West of this syncline are other major folds the details of which have not been mapped.

The lowest rocks (stratigraphically) exposed at the surface in the major anticline are the impure calcareous and dolomitic schists and slates in Deadwood Gulch. Here the westward dips on the west limb of the anticline may be observed. These west dips give way to the prevailing steep easterly dips opposite the De Smet cut, the northernmost extension of the Homestake ore body.

On the geologic map, Fig. 34, are represented, among other formations, the outcrops of a narrow band of quartzite and of several metamorphic dolomitic beds. These beds, with interruptions, may be followed from Bobtail Gulch to the Homestake open cut, and also may be observed in many places underground in the mine. They have been traced also by Wright and Hosted through the great open cut. And some of the details of the folds in which they are involved are also mapped in the major syncline to the west. A shear zone occurs between the major anticline and major syncline. Its position is shown on the geologic map.

The relative position of the various open cuts of the Homestake system of ore bodies (see Fig. 34) is suggestive of the structure which determines their position.

For example, the Caledonia ore body (see No. 1, Fig. 34) is formed by a tightly compressed double fold involving massive beds of cummingtonite schist. All of the details of this folding have not been deciphered, but some of them will be discussed below. The beds involved in the Caledonia open cut are the same as those that may be observed in Deadwood Gulch, and they may be traced, with interruptions, beyond the Caledonia cut to the Claire cut. (See No. 2, Fig. 34.) Thence they pass by folds to the Hercules cut. (See No. 3, Fig. 34.) From the Hercules cut a prominent cummingtonite schist layer can be traced di-

rectly into the great open cut, where it becomes involved in a number of anticlinal and synclinal folds which determine the shape and position of the several remaining ore bodies. (See Fig. 34.)

Enumerated, these ore bodies are: (1) the Old Abe ore body (unimportant except from a structural standpoint); (2) the Incline ledge; (3) the Pierce ledge; (4) the Main ledge; and (5) the De Smet ledge, really an integral part of the Main ledge. (See mine maps, Figs. 39, 40, 41.)

If, for a moment, all the disturbance produced by the Tertiary porphyry and faulting be forgotten, and it be kept in mind that the dolomitic schists do not everywhere make ore, the structure becomes clear in its major features. From the Old Abe ore body the cummingtonite-bearing beds pass by way of a double fold, first synclinal and then anticlinal, into the synclinal fold that makes the Incline ore body. From here the beds pass to the Pierce ore body, which is a tightly compressed anticlinal fold; thence they pass to the main ore body, made up of a number of closely compressed synclinal and anticlinal folds which on their western side are involved in a shear zone. West of this zone these beds again appear in this major syncline and at a number of the places are mineralized. Viewed from this standpoint, viz., as mineralized portions of a series of folded beds of definite stratigraphic position, most of the characteristics of the ore bodies are readily explained.

Studies underground have corroborated surface observations in every particular, and though many places where one might wish to make observations underground were inaccessible, it can be said in general that no observations failed to support the hypothesis of structure suggested by observations on the surface and as set forth above. That is, the underground observations served to elaborate and make clearer the intricacies of the folding which were hidden by reason of surficial cover and igneous intrusion. Thus, for example, it is always possible underground to determine the all-important point, whether the rocks at any particular place in the mine are *below* or *above* the quartzite horizon.

It has been found that the ore-bearing horizon is invariably either immediately or a short distance stratigraphically beneath this quartzite horizon. The beds above the quartzite (garnetiferous schists in the main) are everywhere barren of ore. The carbonate beds beneath the quartzites, however, particularly the cummingtonite rock, almost invariably accompany the ore; in fact, at most places it forms the so-called ore-bearing ledges. It is true that chlorite schists and slates associated with the more highly carbonate rocks do carry gold and are mineralized in places, but this in no way alters the fact that it is this calcareous, magnesium, iron-bearing series of metamorphic rocks that is the locus of the ore.

DESCRIPTION OF STRUCTURE OF TYPICAL MINE LEVELS.

The essentials of the structure of three typical mine levels are presented below:

300 Level.—Much of the 300 level is now inaccessible, particularly the footwall country. (See Fig. 38.) On this level all the various ore bodies appear, which, when connected, prove the folded character of the ore-bearing beds. Here, for example, the suggested connection of the "Old Abe" ledge northwestward and northward with the Caledonia is very clear. The Caledonia terminates to the north in a very sharp synclinal fold. On some levels this feature is more clearly shown.

On this level the ore body, in plan, takes on the distinct appearance of a group of connected synclinal and anticlinal folds. The main portion of the ore body shows an alternation of barren horses and connecting ore-bearing ledges. This arrangement is brought out by the dotted lines. The upper (stratigraphically) of these lines represents the approximate position of the base of the barren quartzite series; the lower (stratigraphically) represents the approximate base of the cummingtonite series—that is, the beds that make ore. The Incline ledge is much broken by porphyry. The De Smet ledge is formed by the single limb of a closely oppressed syncline cut on the west by a shear zone. It

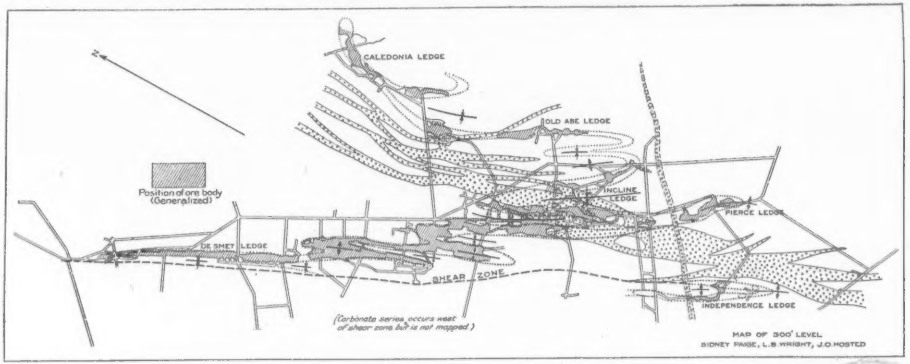
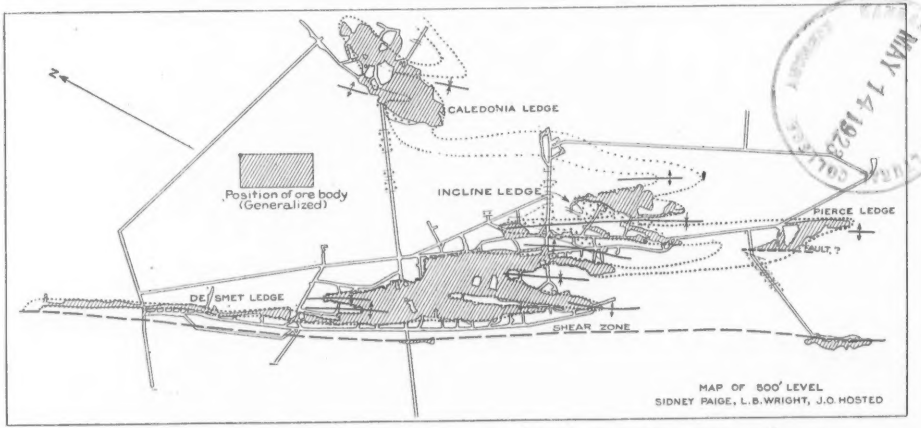


FIG. 38. Map of the 300-ft. level (upper).



MAY 14 1924

FIG. 39. Map of 500-ft. level (lower).

is probable that the Independence ledge, before shearing occurred, connected with the De Smet ledge. The connecting bed is now drawn out and pulled apart. There is evidence to support the view that the Independence ledge is anticlinal in structure.

500 Level.—Much of this level is inaccessible, but the principal structures could nevertheless be made out with a good deal of assurance, for they may be coördinated with levels above and below. (See Fig. 39.)

The Caledonia ore body is considerably thicker than on higher levels. The Incline ledge is still much broken by the invasion of porphyry and the Pierce ledge is still separated from the main ledge. The De Smet ledge remains a single bed—the East limb of a close synclinal fold, the West limb of which has been sheared off.

900 Level.—On the 900 level many of the major folds of the Homestake system are clearly illustrated. (See Fig. 40.)

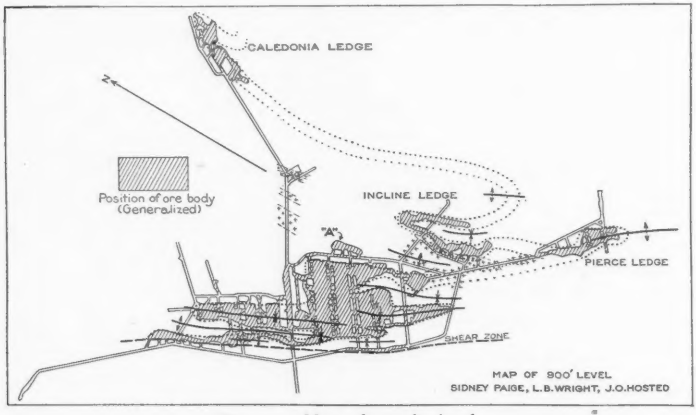


FIG. 40. Map of 900-ft. level.

The syncline of the Incline ledge with two limbs diverging southward may be compared with the Pierce ore body at the southern end of which heavy quartzites appear on both sides of the ledge. This southern end of the Pierce does not show an anticlinal nose

so perfectly as is shown on the 1,000 level, and it is probable that the ore-bearing rock is leaner on this level at this point, and that it was not mined out to the point where the wall rock curves around it. On the 1,000-foot level this is the case. At the south face of the stope on this level the strike of the cummingtonite rock is still parallel to the walls.

The Incline ledge, as may be seen, is bounded on the west by porphyry, which separates it from the Main ledge, of which there can be no doubt it is a part, and it is reasonable to suppose that the small ore body at "A" is a part, and probably the northernmost extension, of the Incline ledge. At the extreme eastern end of the main cross-cut traversing the Incline ledge cummingtonite rock appears, separated from the Main ledge by schist. This cummingtonite rock is probably the same ledge folded over on an anticline. Development on higher levels practically proves this to be true.

The twist in the middle of the Pierce ore body is no doubt due to the same small double fold, so clearly shown on the 1,000 level, but this observation can not be made on the 900, as the ore body is inaccessible at this point.

The narrow anticline at the south end of the main ore body is indicated by the fact that the quartzites cut off and curve around the ore at the south, thus forming the anticlinal nose. These quartzites may be observed in the main cross-cut at the south end of the ore body. Naturally, in such close folding as is here involved, where for most of the distance on the flanks of a fold the dips are in one direction, it is not easy to locate the precise point where the beds turn. But as should be expected, there is a point on the flank of the fold where the dips do become vertical, and such dips were observed in the mine. A nice corroboration of this structure was obtained by locating quartzite in the trough of the major syncline, which lies immediately east of this major anticline. The question may well be raised here: Why do the quartzites not follow the ore closely at all points? In the first place, not all of the potential ore-bearing material is rich enough to be mined; secondly, variations in the composition of beds from

place to place inhibited replacement by solutions; and, thirdly, there is no reason to expect that perfect regularity in replacement would take place.

The trough of this major syncline is clearly outlined by the barren and extensive "horse" that projects northwestward into the main ore body. It must be remembered always that in a mining operation of this type much barren rock must in places be removed and milled in order to obtain the richer portions. Therefore, the configuration of the mined portions of the ore bodies does not in some places conform to the bedding planes of the "carbonate" beds. Also, mineralization is not always confined to exactly the same horizon, but occurs from place to place in a group of beds.

The quartzites on the west side of the main ore body may be observed in the "draw hole" drifts off the main header, but their continuation to the northward is truncated by a pronounced shear zone. This shear zone limits the ore at its west side, at the extreme north end of the main body, and can be followed southward almost to the point where the quartzites end to the northward. It is reasonable to believe that the "shear" has cut off the quartzites and is a major structural feature. Indeed, as pointed out before, this fault or group of faults extends from the surface to the lowest levels.

On higher levels, notably the 500, 600, and 700, there are indications that the folds which constitute the main ore body trend into and are cut off by the footwall fault or shear zone. On the 800, however, the configuration of the mined-out ore suggests that the major folds have swung more nearly parallel with the footwall fault, and it is also difficult to explain the configuration of the 900 level on any other hypothesis.

The interpretation of the structure along the western footwall on this level that fits in best with the most facts is as follows: The quartzites that may be observed along this wall occupy a sharp syncline, the axis of which is indicated on the map. Their termination to the north is due to this synclinal structure. The shear zone passes along and cuts out part of the western limb of

this syncline, and the narrow band of ledge matter shown on the map expresses this fact.

MINERALIZATION.

It has been shown above that the Homestake ledges are a part of a series of folded carbonate-bearing schists, and that the form of the ore body arises from this fact. It will be shown below that the ores are replacement sulphide lodes and the essential features of their mineralogy will be described and illustrated. It is also of practical importance and scientific interest to know the age of the ore deposit. Is it of pre-Cambrian age, Tertiary age, or partly both? Systematic search for new ore bodies should be guided to a considerable degree by the decision reached. Evidence will be presented below, as the ores are described, to show that the ore body was formed in pre-Cambrian time, and that it was probably enriched during Tertiary time—a satisfactory conclusion when it is remembered that this mine is perhaps unique in point of genesis, and among the greatest gold mines of the world.

The Sulphides.—The ores of the Homestake lode invariably carry sulphides and generally in the best ore these are abundant. The sulphides named in the order of their introduction are arsenopyrite, pyrrhotite, and pyrite. Gold is associated with each of these minerals—that is, occurs in them or in gangue minerals near by.

The sulphides have replaced portions of the carbonate schist series. Thus, the deposit can not be described as a vein, nor as a series of sheeted veins. It is distinctly a replacement lode. The distribution of the sulphides in the main conforms to the schistose structure of the rock. In many places they have replaced original carbonate minerals. They follow bedding planes and lines of schistosity, and if one relied wholly upon their general appearance, one would assume at once that they had been intensely compressed and folded with the gangue minerals. While only partly true, it can be shown that, in a measure at least, this is the case, for evidence suggests that the sulphides were introduced before the final stages of the metamorphism.

There is abundant indication that arsenopyrite was the first sulphide to be introduced. Its typical occurrence is illustrated in Figs. 41, 42. In Fig. 41 the sulphide associated with it is

FIG. 41. Arsenopyrite in large angular crystals cut by pyrite. Natural size.)

pyrite; in Fig. 42, pyrrhotite. In both illustrations it may be plainly seen, first, that arsenopyrite characteristically develops

FIG. 42. Arsenopyrite in large angular crystals cut by pyrrhotite. (Natural size.)

with crystal faces, replacing the body of the rock irrespective of the minerals that constitute it, and in Fig. 41 it is particularly clear that subsequent compression and movement has broken these crystals and, by attrition, rounded their edges. On these rounded edges and in cracks in the crystals pyrite has been deposited. (See Fig. 43.) Nowhere was arsenopyrite observed cutting pyrite.

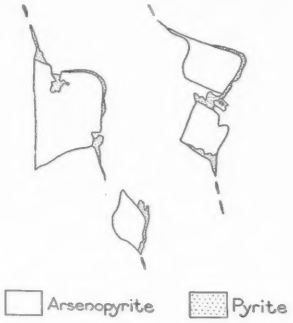


FIG. 43. Pyrite deposited on rounded edges of arsenopyrite.

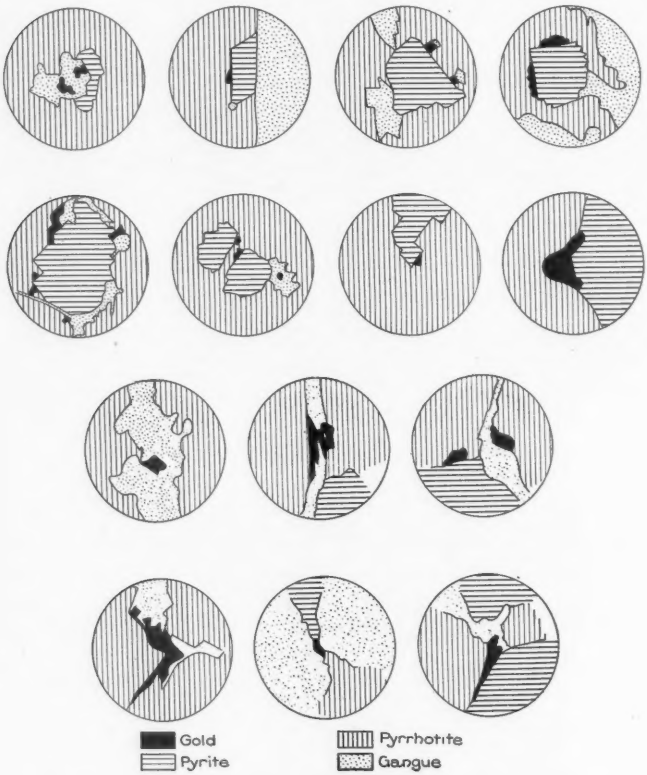
In one of these specimens pyrrhotite bears precisely the same relations to arsenopyrite that pyrite bears in the other specimen. Nowhere was arsenopyrite observed cutting pyrrhotite. It follows, therefore, that pyrrhotite is also later than arsenopyrite.

These observations seem to establish the fact that arsenopyrite was introduced at a late stage of the metamorphism of the schists, that this mineral was partly deformed, and that shortly afterwards pyrrhotite and pyrite were introduced.

It may be readily shown that pyrite is later than pyrrhotite. Pyrite occurs replacing pyrrhotite, as veinlets cutting pyrrhotite, and fills angles in groups of pyrite crystals. In Figs. 44 and 45 some of these relations are illustrated.

Of special interest is the discovery of two generations of pyrite. Veinlets of pyrite were observed cutting pyrite grains of the first generation. Inasmuch as it is known that great quanti-

ties of pyrite were deposited in Cambrian beds overlying the Homestake lode, it is gratifying to find concrete evidence of the second generation in the Homestake ore.



FIGS. 44 and 45. Illustrating relations of pyrite and gold to pyrrhotite.

There is further evidence strongly supporting the view that primary mineralization was pre-Cambrian in age. An important zone of shearing follows the western side of the main ore body.

It has been shown above in the discussion of structure that this shear zone is related to close folding and is pre-Cambrian in age. It occurs where a closely appressed anticline abuts against a major syncline. On several levels, particularly the 900, a mashed zone of slate, in places two feet wide, may be observed in a position corresponding to the position of this shear zone. Within this two feet of mashed slate, intense folding, shearing, and mashing has deformed the sulphides, pyrrhotite, and pyrite, and also the gold. Masses of pyrrhotite are sheared at their edges and drawn out in a finely divided state and mixed with slate. Gold has suffered similarly. The whole proves a movement under severe compression. The occurrence is illustrated in Fig. 46.

FIG. 46. Illustrating the compression and shearing of pyrrhotite, pyrite and gold during pre-Cambrian folding.

No such forces as are indicated here have operated in this region in Tertiary or later time. On the contrary, it is probable that tensional stresses rather than compressional were dominant at that time.

The Occurrence of Magnetite.—The occurrence of magnetite later than pyrite is further supporting evidence of the pre-Cam-

brian age of the primary mineralization. It is developed as fringing masses and crystals around pyrite grains, filling reentrant angles in groups of pyrite crystals, and cutting or replacing crystals of pyrite. Magnetite has not been noted in the Tertiary ores overlying the Homestake lodes. But it is a common mineral associated with the granitic invasion of the Southern Hills both in pegmatite and quartz veins. The writer regards it as of this association in the Homestake ores and, therefore, as further proof of pre-Cambrian age of the deposits.

The Occurrence of Gold.—Most of the gold in the Homestake ores occurs in the free state and about 70 per cent. of it is caught by amalgamation. Polished sections of sulphide ore almost invariably show free gold. This gold may be in the gangue minerals, as thin flakes, for example, along the cleavage surfaces of chlorite, or it may be in quartz or in carbonate; or, as in many places, it may be more closely associated with sulphides. It has been noted in arsenopyrite, in and on the borders of pyrite grains, and abundantly replacing or accompanying pyrrhotite.

In Figs. 44 and 45 is illustrated the occurrence of gold associated with pyrite and replacing pyrrhotite. It is noteworthy that in many instances the gold occurs at the borders of the pyrite grains, but inside of the pyrrhotite.

The relations of gold and pyrrhotite to arsenopyrite are illustrated in Fig. 47. Gold and pyrrhotite later than, but associated with, arsenopyrite at the borders are also shown. Gold in veinlets cutting pyrrhotite or between the latter and pyrite are illustrated in Figs. 44 and 45. A number of drawings from Sharwood [8] illustrate the occurrence of gold.

It seems probable from these illustrations that gold came in with both pyrrhotite and pyrite, in pre-Cambrian time, and that probably some very fine gold possibly associated with telluride was introduced in Tertiary time—thereby enriching the pre-Cambrian deposit.

The introduction of the sulphides and gold in pre-Cambrian time is conceived of as directly related to the last stages of meta-

[8] *Op. cit.*

morphism of the schists and connected with the invasion of granite. The statement that the sulphides appear in a certain sequence expresses their dominant relationships. It is probable that no great time interval separated the introduction of the sev-

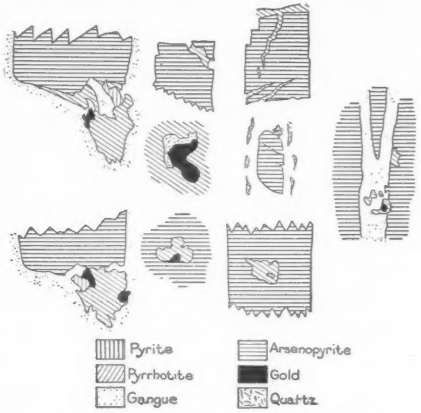


FIG. 47. Relation of pyrrhotite and gold to arsenopyrite.

eral sulphides and the gold: that some gold was introduced with pyrrhotite, and more later with pyrite. Quartz also was no doubt introduced at several stages, or continuously, and silicates making up the body of the rock were no doubt undergoing change throughout a considerable period, while sulphides were being deposited.

DIFFERENCES BETWEEN THE TERTIARY GOLD ORES[9] IN CAMBRIAN DOLOMITES AND ORE OF THE HOMESTAKE LODE.

Inasmuch as the Homestake ores might be considered of Tertiary age, it is important to point out that there are striking differences between the gold ores of Tertiary age that replace the Cambrian dolomites overlying the Homestake lode and the ores of the Homestake lode itself.

[9] For a very complete description of the Tertiary siliceous ores see Irving, J. D., *op. cit.*

These differences are of two sorts: First, the differences of mineralogy, emphasized by the need of different metallurgical treatment; and, second, differences in silver-gold ratio of the bullion. The Tertiary ores, which occur in certain areas where vertical fractures traverse the Cambrian dolomites and sandstones, are pyritic replacement deposits carrying varying, but always minor amounts of arsenopyrite. Both pyrrhotite and magnetite, the former so important in the Homestake lode, the latter shown to be later than pyrite, in the Homestake ores, are absent.

The gold of the Cambrian ores (excepting the conglomerate ore, discussed further below) is "so fine (fine particles) that no gold could be obtained in the pan, an almost universal characteristic of these ores." [10]

This is quite the opposite from the condition in the Homestake mine, where much gold—70 per cent., more or less—is readily caught by direct amalgamation.[11]

The explanation of this difference rests on this fact: that in the ores of Tertiary age the gold occurs principally as a telluride, whereas in the pre-Cambrian ores at least 70 per cent. is free gold. F. R. Smith[12] has shown that tellurium is an important constituent of the Tertiary ores and suggests that sylvanite is probably the telluride present.

In the Homestake ores tellurides are rare, though they have been noted. It is possible that that portion of the gold caught by cyaniding may be present partly in the form of tellurides.

Notable differences are noted by Sharwood[13] between the silver-gold ratio of Tertiary ores in the vicinity of the Homestake lode and the silver-gold ratio of the Homestake ore. Ratios of 5, 10.58, 11.4, 4.1 were noted in the Tertiary ores, whereas in the Homestake ores the average is about 0.215 for bullion caught on the plate and about 0.433 for bullion recovered by cyaniding.

[10] Devereaux, W. B., "The Occurrence of Gold in the Potsdam Formation, Black Hills, Dakota," *Trans. Amer. Inst. of Min. Eng.*, vol. 10, p. 475, 1881–2.

[11] Sharwood, W. J., *op. cit.*, p. 775.

[12] Smith, F. R., "The Potsdam Ores of the Black Hills of South Dakota," *Trans. Amer. Inst. of Min. Eng.*, vol. 27, pp. 404–428, 1897.

[13] *Op. cit.*

Further evidence supporting the view that the Homestake ores are pre-Cambrian lies in the fossil placer deposits in Cambrian conglomerates. In this connection it is desirable to weigh the evidence pointing to the existence of a pre-Cambrian ore body cropping out at the time Cambrian conglomerates, sandstones, and dolomites were laid down. That is, the validity of the statement that fossil placer deposits derived from the Homestake lode occur in the basal Cambrian conglomerates.

J. D. Irving,[14] following W. B. Devereaux,[15] has presented evidence to show that fossil placers actually existed, but an impartial and critical review of Irving's statement and the facts that he presents raises doubts not as to the probabilities of the case, but as to the conclusiveness of the argument on the basis of the conglomerate ores alone. The main points made by Devereaux and Irving will be very briefly presented.

In describing the gold-bearing conglomerates Irving says:

> At the base of the series of Cambrian Strata which lie unconformably upon the upturned metamorphic schists of the Algonkian, a conglomerate is usually present. It varies in thickness from a few inches to more than 30 feet. At a few localities it is entirely absent, but in general is so prominent a feature of the series that it has been recognized as a separate formation. . . . There are two localities where it attains an unusual thickness. The first is known as "Cement Ridge" and is on the west side of Spearfish Canyon; the second is the region in and about Lead. In the latter locality only, it is auriferous and has yielded large amounts of gold. The conglomerate is overlain by cross-bedded beach sands and quartzites, which are in turn conformably overlain by the higher members of the Cambrian series. It is underlain unconformably by metamorphic schists and slates. In these underlying Algonkian rocks is a great mineralized zone of relatively indurated character, which strikes approximately N. 34° W. . . . This zone was probably a reef in the old Cambrian sea at the time of the deposition of the conglomerates, as it offered more resistance to erosion than the encompassing schists on account of the hardness imparted to it by pre-Cambrian mineralization. . . . The gold-bearing conglomerate occupies depressions in the old

[14] Irving, J. D., and Emmons, S. F., "Economic Resources of the Northern Black Hills, Part II., *Min. Geol.*," U. S. Geol. Survey, Prof. Paper 26, 1904.

[15] Devereaux, W. B., "The Occurrence of Gold in the Potsdam Formation, Black Hills, Dakota," *Trans. Am. Inst. Min. Eng.*, vol. 10, pp. 465–75, 1881–2.

Algonkian surface, but thins out to nothing along the strike of the Homestake lode, where the higher measures of the Cambrian lap over onto the mineralized rocks of the Algonkian. . . . Lithologically this auriferous conglomerate is formed of rounded waterworn pebbles of quartz or Algonkian quartzite with an intersprinkling of schist fragments which seem to decrease in abundance as one proceeds farther from the Homestake lode. It may be at once distinguished from the non-gold-bearing portions of the basal conglomerate, as it is cemented by either oxide of iron in the weathered portions or by pyrite when it has not suffered alteration. The non-auriferous conglomerate, on the other hand, has always a quartzitic, or in rare instances a slightly calcareous matrix. The pyritic cement occurs in all the productive areas except one, and as all degrees of oxidation are present it can be assumed that the matrix of all the gold-bearing conglomerate was once pyrite.

Much of the gold in the richest conglomerates is detrital, as proved by its water-worn condition and its concentration near the bed rock. This gold was derived undoubtedly from the erosion of auriferous lodes in the Algonkian rocks and was mechanically deposited in depressions along the old Algonkian shore line. Some of the gold was dissolved by ferric sulphate resulting from the oxidation of the pyrite, and from this solution was redeposited in thin films in the schists below. This has also produced an enrichment of the lowermost layers of conglomerate.

Up to this point it is clear that Irving regards gold in these deposits as of detrital origin. His next statement is the first to cast doubt upon this hypothesis. He continues:

"In addition to these it is possible that gold was introduced with the pyrite that once formed a large portion of the matrix of the pebbles. To determine this careful assays were made in the only productive area now completely accessible. . . . It was found that along definite lines in the center of the stopes there were values of from $5 to $12 per ton in the conglomerate, while at a distance of from 10 to 100 feet from such lines the values sink to between $1 and $2 per ton. Iron-stained fractures are found in the roofs of these stopes. A possible inference is that the gold which has low and fairly uniform values distributed through the mass is of detrital origin, and that the additional values have been introduced into the conglomerate together with the pyrite along zones of fracture. This is rendered still more probable by the fact that much of the gold does not yield to simple amalgamation, the conglomerate being treated largely by the cyanide process. The introduction of the pyrite was subsequent to the deposition of the conglomerates, since mineraliza-

tion extends into fractures in the quartz pebbles. The pyrite is probably a replacement of the original cementing material which elsewhere consists of quartzose sands."

Intrusions of rhyolite cut the conglomerate in some places. They are much mineralized with pyrite, which is thought to be of post-intrusive origin. This would place the pyrite mineralization subsequent to the rhyolite intrusion. He sums up:

"These gold-bearing conglomerates must have been either of fluviatile or of littoral origin. All of the evidence is in favor of the latter view, for (1) the rocks immediately above the conglomerates contain marine fossils and were unquestionably deposited in an extensive Cambrian sea; (2) the area covered by the heavy conglomerates is very small and quickly passes in all directions into regions where finer material with marine shells shows that the conditions were marine; hence, a land surface sufficient to support a drainage extensive enough to deposit such heavy conglomerate could hardly have existed; (3) cross-bedded sands and quartzites were deposited upon the conglomerates with perfect conformity so that they are to be considered as an integral part of a typically marine series; (4) conglomerate is absent from the outcrop of the Homestake lode which must, therefore, have projected above the old pre-Cambrian surface; (5) schist fragments, such as could only have been preserved near the source from which they originated, decrease in abundance as one proceeds outward from the Homestake lode. While, therefore, these were littoral deposits they were exceptional in that they were not uniformly deposited along the shore, but were confined to the vicinity of the outcrop of a large gold lode, and the detrital material from that lode was held in irregular depressions in the submarine surface in its vicinity.

To quote a description of these deposits directly from Devereaux:[16]

In general we find much the same variations of quantity as are shown in the ordinary gravel placer. The local channels referred to show the same alternations of rich and poor material, due to different conditions of current, and the universal occurrence of the greater part of the gold near the bed rock. In general only five or six feet in thickness will pay for mining and milling. . . . The gold has all the characteristics of placer gold and was generally what is called shot gold or smooth, rounded grains, slightly flattened. I observed one nugget of nearly three pennyweights in weight.

[16] *Op. cit.*, p. 468.

The cementing material of the conglomerate was generally oxide of iron and the gold which had lain on bedrock was often attached to the overlying boulders by this medium. In general where conditions had been such as to allow the subsidence of other materials of high specific gravity, the gold was most abundant, ordinarily with large quartz boulders, or with pebbles of hematite. The latter were seldom found without gold being attached to themselves having a smooth, polished surface. In general the position of the gold was always such as to point to its great specific gravity as the locating cause, and not to solution or precipitation. . . . The fineness of this gold is greater than that of the quartz veins, as is generally the case with placer gold.

With the facts thus far seen to be in accord with the position taken, we have another source of proof, in that we find in these same conglomerates, gold which has undoubtedly been precipitated from solution *in situ*. I have several times split open pieces of decomposed talcose schist, and found in the cleavage plane a continuous thin film of gold. Moreover, the schist underlying one of these deposits has been found to carry sufficient gold to pay for milling, although after a depth of 10 feet has been obtained, it seems to give out. Specimens from this locality show the gold in thin flakes, seldom coarse and pan tests show the gold to be fine like chert. On the other hand, where the slate has been very soft cement gold will be found to have worked down into the crevices for several feet. It can be washed out in a pan from the fragments without crushing and then appears smooth brown gravel so continuous in the coating of red oxide of iron. In addition we have gold undoubtedly precipitated in the quartzites of this series at a period much more recent and this gold presents none of the characteristics of the cement gold.

It is apparent to the critical reader of Irving's and Devereaux's reports that arguments for placer gold, based on evidence of reprecipitation by downward solutions, would equally well apply to gold that had been introduced into the conglomerates with pyrite. For such gold might also be reworked. But many of the facts presented above suggest strongly that placer gold actually existed. These may be summarized as follows:

There is a stratigraphic proof that a pre-Cambrian reef existed along the outcrop of the Homestake lode. The conglomerates were derived from this reef.

The conglomerates carried coarse gold said to resemble detrital gold from other places and its location was apparently both within

the conglomerate and below in the bedrock carried there by gravity—*i.e.,* its position was due to its weight. The gold, too, carried less silver than the lode gold.

The gold in the Cambrian formation everywhere except in the conglomerates is extremely finely divided and most of it can not be recovered by amalgamation at all. The heavy matrix of pyrite (or limonite where oxidized) that accompanies the gold-bearing conglomerates suggests that the conglomerates were derived from a pyrite-bearing lode, though it is problematical whether all the pyrite would not have been oxidized, and it is probable that following the invasion of these rocks by Tertiary volcanics, and the passage through them of a certain amount of gold-bearing solutions derived from the porphyry, that the detrital pyrite may have been introduced.

My interpretation of Irving's somewhat conflicting statements is that placer deposits did exist, and that they were enriched in Tertiary time by the same solutions that formed the refractory siliceous ores that replace the Cambrian dolomites in a number of places.

SEARCH FOR NEW ORE BODIES.

The conclusions reached regarding the nature and origin of the Homestake ore body can be applied directly in the development of the ore body, and in the search for new ore bodies. The approximate position of the ore-bearing beds, those favorable to ores, can be determined by structural and stratigraphic studies on the surface and underground. Drilling and workings should be directed according to such studies.

The influence of porphyry as a possible enricher of the pre-Cambrian ore should be a subject of continued study.

Those geologic factors that favorably affect the location of ore may be summarized as follows:

1. The metamorphic carbonate beds carrying cummingtonite have so far proved the best ore carriers. They are overlain by barren quartzites and schists. These overlying beds were unfavorable to ore deposition and may have impounded solutions,

thus favoring concentration of ore in the immediately underlying carbonate series.

2. Close folding, with the consequent thickening of the favorable beds, produces a large body of replaceable rock.

3. Shearing favored the deposition of abundant sulphides and abundant sulphides generally accompany ore.

4. Enrichment is probably greatest near Tertiary porphyry.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

DISCUSSION.

J. E. Spurr: I understand that the ore of the Homestake mine is largely pre-Cambrian in age. I understand also that there has been in this general region a notable post-Cambrian mineralization. It seems a very remarkable conjunction of phenomena that there should have been pre-Cambrian and Tertiary mineralization in the same mine. I think it calls for some explanation. It does not often happen.

S. Paige: The question that Mr. Spurr raises is an interesting one, if the long geologic history of the Black Hills be considered. It is probable that in very early pre-Cambrian times a great dome existed in the region of the Black Hills. Such a possibility is suggested by the folding of the schists around the great Harney Peak granite mass in the southern hills. The introduction of gold-bearing veins associated with the granite and the formation of other mineral deposits of value occurred at this time. A study of the Homestake ore body proves in my opinion that this great lode owes its origin to solutions connected with the invasion of the afore-mentioned granite mass or to deep-seated similar masses far beneath the present Homestake mine.

The present doming of the Black Hills and invasion by Tertiary porphyry is clearly a very much later event and possibly may have been caused by the movement into place at great depth of some large igneous mass, of which the Tertiary porphyries are but an expression. Important sulphide and gold mineralization closely followed the invasion of these porphyries and replacement ore bodies were formed within the flat-lying Cambrian dolomites. The vertical fractures that fed the transverse flat-lying Cambrian beds passed downward into the schists, but where this happens the schists are generally barren of ore; that is, they were not readily replaceable by the ore-bearing solutions. It so happens, however, that the great Homestake lode owed its origin to the presence of

dolomitic and calcium carbonate beds, readily replaceable rocks, and where the late Tertiary verticals or fissures pass upward through the ore body, it is natural to suppose that a certain amount of gold was deposited, enriching the previously formed Homestake pre-Cambrian lode.

As I have shown in my paper, there are marked differences between the ores deposited in Tertiary time in the Cambrian rocks and the ores deposited in pre-Cambrian time in the pre-Cambrian rocks of the Homestake lode.

SOME MOTHER PLANTS OF PETROLEUM IN THE DEVONIAN BLACK SHALES.

DAVID WHITE AND T. STADNICHENKO.[1]

GENERAL DESCRIPTION OF THE MATERIAL.

In the course of the examination under the microscope of some of the richly bituminous shales from the older geological formations for the purpose of gaining information as to the source of the petroleums generated naturally or by artificial distillation from these shales, two types of plant fossils are found to be of unusual interest and economic importance. Both occur in black shales, regarded as of Genesee age, in northeastern Kentucky.

One of these plants is represented by forking divisions or thalli of a small seaweed, here named *Foerstia*. In the fronds of this plant the walls of the outer zone of cells are seen under the microscope to be thickly reinforced with reddish-brown matter, apparently of waxy-resinous composition. Overlying the surface of the plant is a pavement of translucent, lemon-yellow, waxy secretion, somewhat similar in composition to the reddish-brown underlying deposits, but rather sharply differentiated and clearly distinguishable chemically as well as by color. The small thalli, the cell structure of which is distinct and remarkably striking, as seen by transmitted light in the treated preparations, were evidently fortified against exposure to the air for considerable periods. The waxy or "waxy-resinous" protective secretions, which were especially designed to resist decay, render the bitumized and partially carbonized remains so tough and leathery that in some cases they may be lifted from the surface of the rock and subjected to experimental tests with solvents and reagents, as well as to study under lenses of moderate power. The super-

[1] Published by permission of the Director of the U. S. Geological Survey.

Presented before Society of Economic Geologists, Ann Arbor Meeting, December, 1922.

ficial aspect of these minute thalli strongly suggests the scaly or semi-warty appearance of the common species of "rock weed" or *Fucus* of the Atlantic Coast. The mode of occurrence of the egg cells or spores reminds one of the brown algæ. The secretion of fatty substances in the cells of some representatives of the latter class of plants is well known.

The other fossil that is of unusual interest from the petroleum standpoint is represented by innumerable small roundish spore sacks, now flattened and appearing as somewhat wrinkled or creased, irregularly rounded bodies, 3 to 5 mm. in diameter. These spore cases, the form and structure of which suggest their growth in the axils of leaves or bracts of some ancient relative of the modern Lycopods, are found under the microscope to have been provided with several outer layers of cells the walls of which, somewhat as in *Foerstia,* are provided with thick, russet-orange reinforcement of some waxy or, possibly, somewhat resinous substance. Likewise, the outer surface of the spore case is decked with a thin layer of extremely pale yellow or straw-colored waxy matter, highly refractive to the light. The structure of the walls of these spore sacks is beautifully revealed in the preparations made by the junior author, but the inner tissues, not having been protected by decay-resistant secretions, have disappeared. That the fossils are sporangia of some Paleozoic plant is evident, though no spores have definitely been recognized in the interiors of the specimens here examined. From the structural characters and the evidence as to the mode of attachment, in which the fossils resemble certain spore cases of the Carboniferous *Sigillaria,* it is provisionally assumed that they belong to one of the Devonian types antecedent to the Carboniferous Lepidodendra and Sigillariæ. The fossils in hand are tentatively referred to the genus *Protosalvinia,* for there is little doubt as to their generic identity with the carbonized plant remains from the Devonian of Brazil and Ohio, described by Dawson under that name. They can, however, bear only remote relation to the living *Salvinia.*

The evidence of the leathery, decay-resistant protective matter in *Foerstia* and *Protosalvinia,* pointing to the necessity of sur-

PLATE V.

Foerstia ohioensis, n. sp., D. W.

FIG. 1. Natural size. Fragment of bifurcating thallus removed from matrix. Though treated in hydrofluoric acid at 50°–60° C., for 2 days, the specimen is still opaque. FIG. 1-*a*. Same specimen, × 2.

FIG. 2. Natural size. Fragments of thalli removed from matrix but still comparatively opaque, though subjected to alcohol for 2 days after treatment with hydrofluoric acid as before.

FIG. 3. Natural size. Pincer-shaped and fertile lobes. Details, enlarged, in Fig. 8.

FIG. 4. Oblong type of lobe still opaque, though removed from matrix. × 2.

FIG. 5. Natural size, shows incurved and overlapping ultimate lobes each suggesting bishop's crozier.

FIG. 5-*a*. Same specimen, × 2.

FIG. 5-*b*. Same specimen, × 22, to show leathery aspect of thallus, size and form of cutaneous cells, the external surfaces of which are decked with convex pavement of lemon-yellow waxy protective secretion.

FIG. 6. × 2, to show pincer-like form of division of thallus.

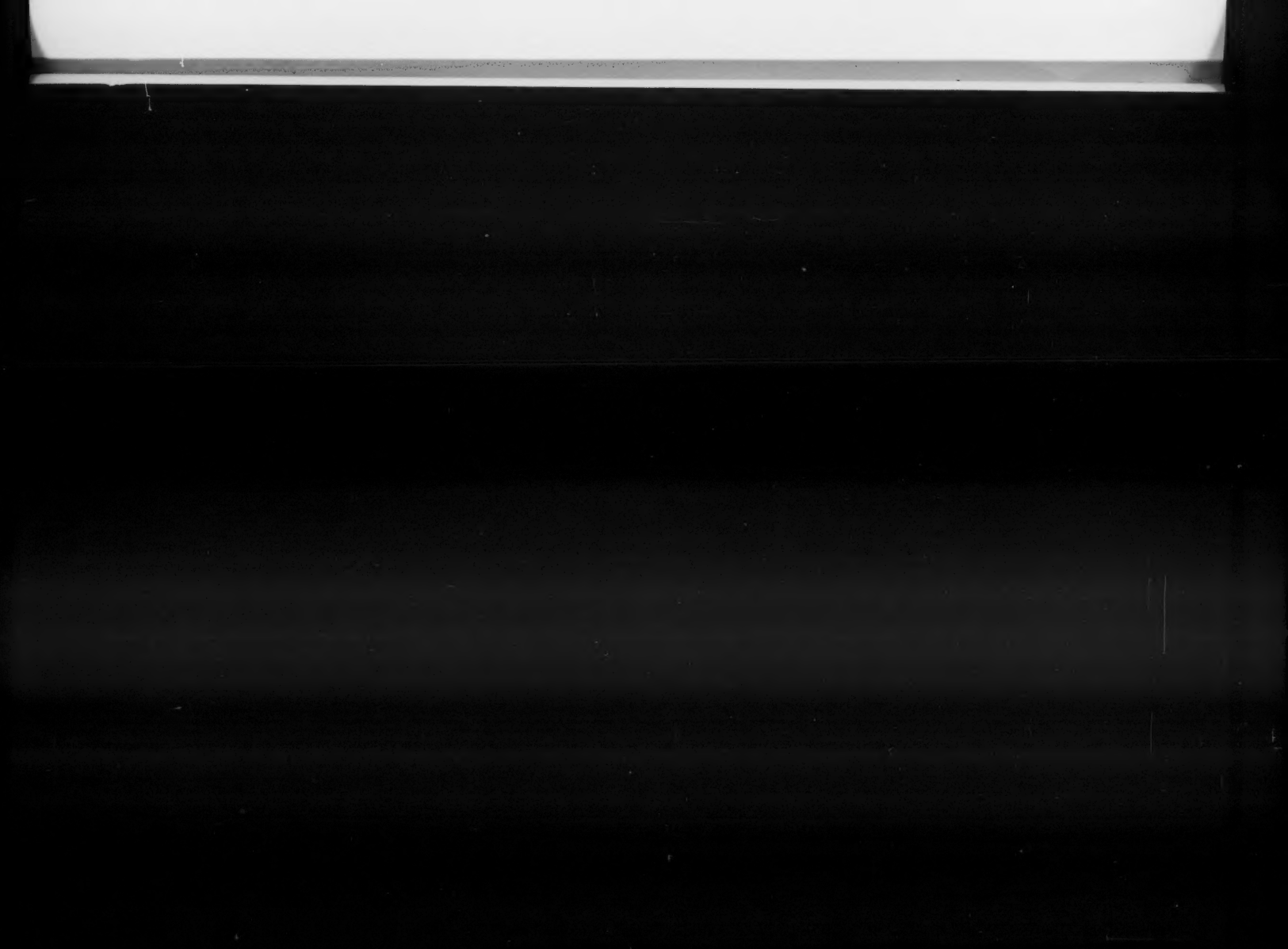
FIG. 7. Fertile bifurcating thalli at *a*. Small or young pincer type at *b*, at the right of which is fertile lobe. × 2.

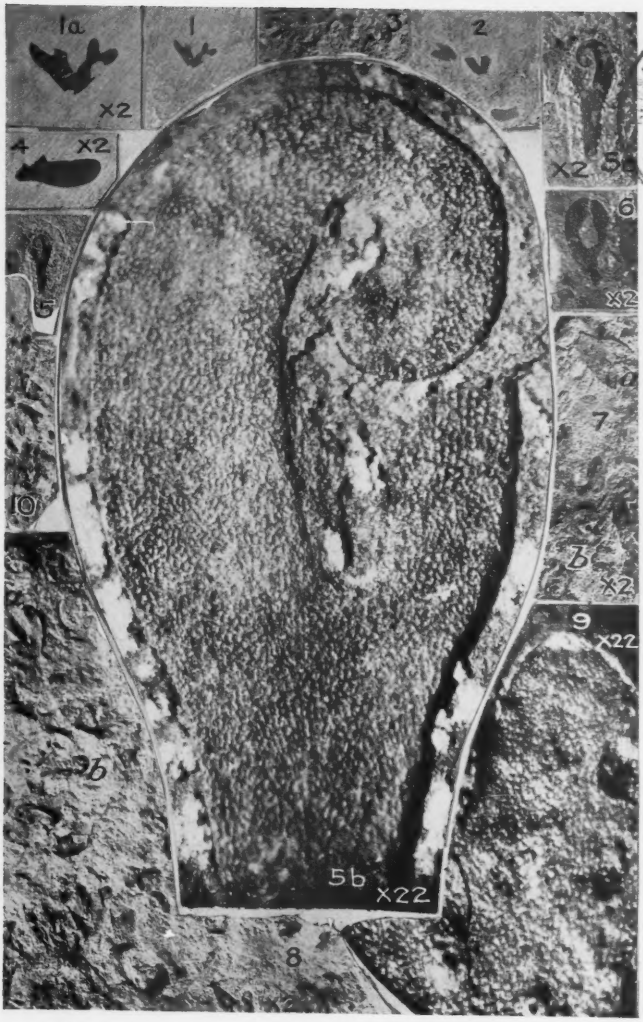
FIG. 8. Showing pincer-like thallus at *a* with impression of another immediately on right. Numerous fragments of thalli in lower part. The pits on fertile lobe at *b* mark positions of the oögonia or conceptacles. × 2.

FIG. 9. Surface of lobe showing positions of oögonia, in 2 longitudinal rows in the leathery lobe. × 22.

FIG. 10. Natural size. Fragments of lobes, one, near middle, is elongated and bifurcating. This type is associated with the pincer and bishop's crozier forms, and may represent a species distinct from bifurcating type in figs. 1 and 2.

Figs. 3, 7, 8, and 10 from specimens, No. 4592, in the geological collections of Western Reserve University; kindly loaned by Prof. J. E. Hyde. All other specimens from the lower 100 feet of the Ohio shale near Vanceburg, Ky.





STATE AGRICULTURAL COLLEGE
MAY 14 1923
LIBRARY

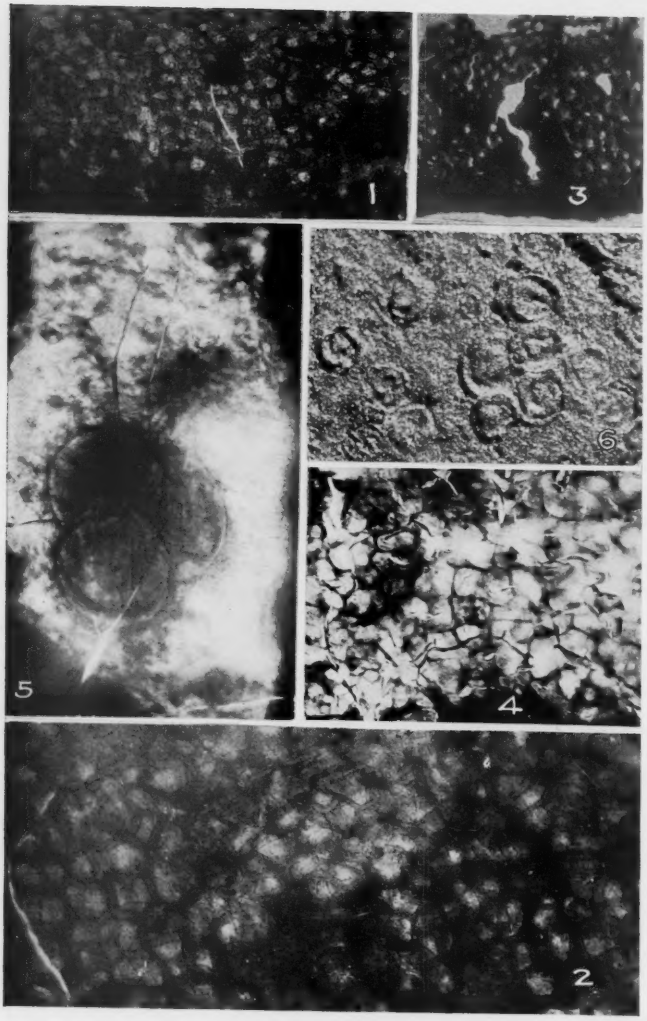

1
3
5
6
4
2

PLATE VI.

FIGS. 1–5. *Foerstia ohioensis*, n. sp., D. W. FIG. 6, *Sporangites huronensis*, Dawson?

FIG. 1. Wall of *Foerstia* thallus after treatment for 2 days in Schultz's reagent at 50°–60° C. Dense patches of humic or incompletely oxidized matter appear opaque. White spots mark points at which outer lemon-yellow cutaneous covering of the leathery thallus, shown in Fig. 5-*b*, Pl. V., is seen through the interiors of the subjacent reddish-brown-walled cells. ×40. FIG. 2. Same specimen, ×75. Shows several layers of subcutaneous cells of thallus wall. Traces of original cell laminæ on left. White patches are views through to lemon-yellow cutaneous layer

FIG. 3. Fragments of cell wall of *Foerstia* thallus from which, after preliminary treatment with Schultz's reagent, the lemon-yellow cutaneous decking has been dissolved by boiling 1 hour in pyridin, leaving only a reticular mesh residual from the reddish-brown thickening of the subcutaneous wall cells. ×25.

FIG. 4. Fragment of thallus wall which, after treatment with Schultz's reagent, was subjected for 5 minutes to a 2 per cent. solution of KOH. After washing, the brown subcutaneous matter was removed, leaving only the lemon-yellow waxy cutaneous surface layer, here seen as a mosaic which indistinctly outlines the pattern of the subjacent cells. ×40.

FIG. 5. Portion of fertile *Foerstia* thallus, after treatment for 2 days with hydrofluoric and nitric acid. Four pale yellowish and slightly resinous or waxy-resinous egg cells are here seen nearly, if not exactly, in place, in the thallus though the wall of the inclosing oögonium has disappeared. The position and distribution of oögonia are shown in Figs. 9, 7 (*a*), and 8 (*b*) in Pl. V. Five groups of immature egg cells form a row on one side of the fragment of thallus, a portion of which is shown in Fig. 5. The cells of the thallus wall are obscurely indicated in upper left. ×90.

FIG. 6. *Sporangites huronensis* Dawson? Occurs in great abundance with several types of smaller spores, in lower part of the Ohio shale, in portions of which it completely covers the bedding planes. ×22.

Figs. 1 to 5 from the lower 100 feet of the Ohio shale near Vanceburg, Kentucky. Fig. 6 from same stage at Ravenna, Ky.

viving periods unfavorable for living and the reproduction of their species, finds support in the waxy covering of the egg cells or spores of *Foerstia* even while enveloped in the mother thallus.

Both the algal thalli, *Foerstia,* and the spore sacs, *Protosalvinia,* are well adapted, on account of their size and preservation, to special micro-chemical study, in which the junior author has subjected the partially bituminized remains to a preliminary series of tests by various solvents and reagents to determine their probable original nature, some qualities of their present composition after having been changed more or less under geologic influences, and their behavior under solvents and heat treatment. These experiments show distinctly the chemical differentiation of the brown and yellow waxy or waxy-resinous deposits. The results of the micro-chemical studies, which are incomplete, are but briefly referred to in this paper, in which the chemical discussion is based on notes furnished by the junior author. The chemical experiments will probably be more fully described in a later publication following the continuation by her of this line of interesting, as well as profitable, investigation.[2]

The thalli of the alga *Foerstia,* though abundant at certain localities, do not appear to be so widespread as the spore cases, which have at places been found in very great numbers, completely covering the bedding planes of the shale and even accumulating in carbonized mats. Associated with both types, and, in fact, extremely widely distributed through the Devonian black shales and in the overlying shales now referred to the basal Carboniferous, are great numbers of resinoid or hard wax-like spore exines, referred to *Sporangites* by different authors, some of whom, notably Orton and Dawson, regarded them as the source of the Devonian oils of the northern Appalachian States. Both the *Sporangites* and the fossils here discussed under the name

[2] The senior author is responsible for the introduction, the paleontology and geology of this preliminary report. For the chemical studies and their interpretation, as well as for the microscopical preparations he is indebted to the junior author, whose resourceful skill has also made possible the recognition in detail of the structural characters of these fossils.

Protosalvinia Ravenna are certainly important sources of artificial oil obtained by distillation of the shale. Accordingly, their office in the generation of petroleum in the course of elapsed geologic time can not be doubted. As pointed out by Orton and Dawson, the *Sporangites* deposits are enormous in aggregate quantity in the black shales of Ohio, and in places are so concentrated as to compose beds from a few centimeters to several feet in thickness and so fatty with the organic matter as to be readily lighted with a candle. The *Sporangites,* which appear to be the decay-resistant walls (exines) of some type of megaspores, possibly of Lycopod affinity, are undoubtedly somewhat different in composition from the plant secretions found in the walls and coatings of *Protosalvinia* and *Foerstia.* All of these plant products especially resistant to decay were originally and are at the present moment characteristically high in hydrogen, and, like the wax-resin series, relatively low in oxygen. Failure to respond to ordinary resin and wax solvents without preliminary treatment is due to alteration, or, as it is called, bituminization. They are by chemical composition particularly adapted to the generation of the hydrogen-rich hydrocarbons, namely, the petroleums, and this is shown by the high grade of the oil obtained from them by distillation. They are, in fact, related in composition to the rich algal coals or so-called bogheads which are paramount in interest, if not importance, as mother rocks from which distillates approaching most nearly to present types of natural petroleum may be obtained.

In addition to the more readily visible and more easily studied bituminized remains of plants found fossil in these shales, there is evidence, here and there, of large amounts of more or less fibrous or spongy plant material of waxy or resinous aspect, in which no cell structure has yet been clearly seen. This material, which was certainly deposited at the time the beds were laid down and can not be explained as any impregnation of the strata by waxy hydrocarbons, is likely to belong to some of the lower orders of plants, probably algæ, and it may ultimately be found

PLATE VII.

Protosalvinia Ravenna, n. sp., D. W.

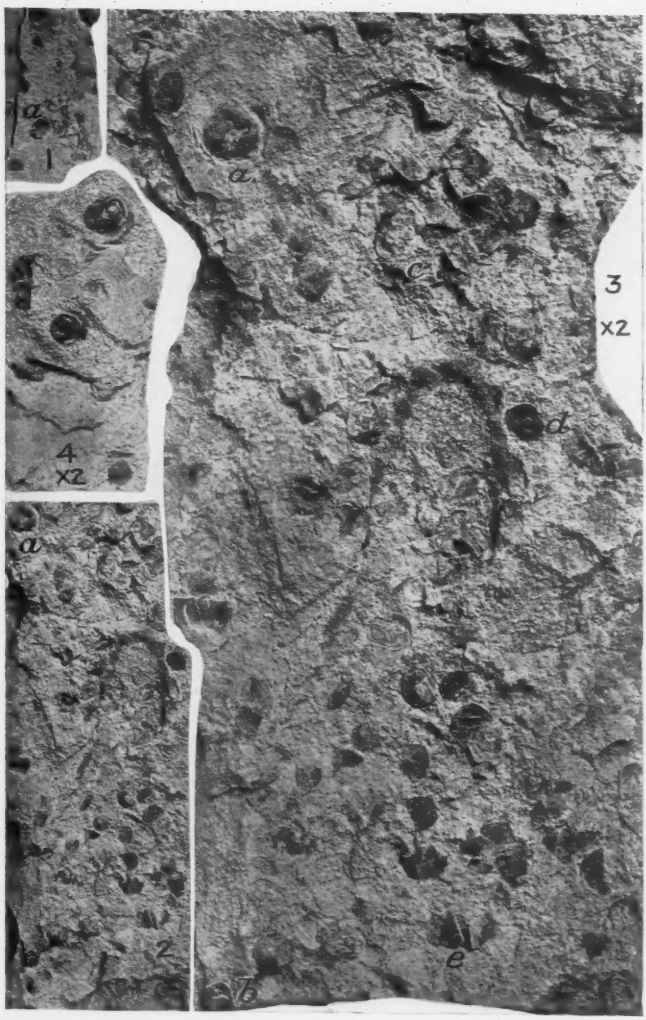
FIG. 1. Natural size. Flattened sporangia on small fragments of gray shale. Specimen marked *a* is shown enlarged in Pl. VII., Fig. 2.

FIG. 2. Natural size. Shale with numerous sporangia; matted in part of specimen. They are thinner and less leathery than the thalli of *Foerstia*.

FIG. 3. Portion of specimen of Fig. 2, × 2. *a*. Sporangium with tetrad aspect, but indentation toward the right is axial, the cushions above and below it being lateral, as shown in Pl. IX., Fig. 1. *c* shows axial features and rupture, the latter illustrated more clearly in *b*, *d*, and *e*.

FIG. 4. Collapsed and wrinkled sporangia with rupture of large specimen on left. × 2.

All specimens from basal portion of Ohio shale at Ravenna, Ky.



KANSAS STATE AGRICULTURAL COLLEGE
MAY 14 1923
LIBRARY

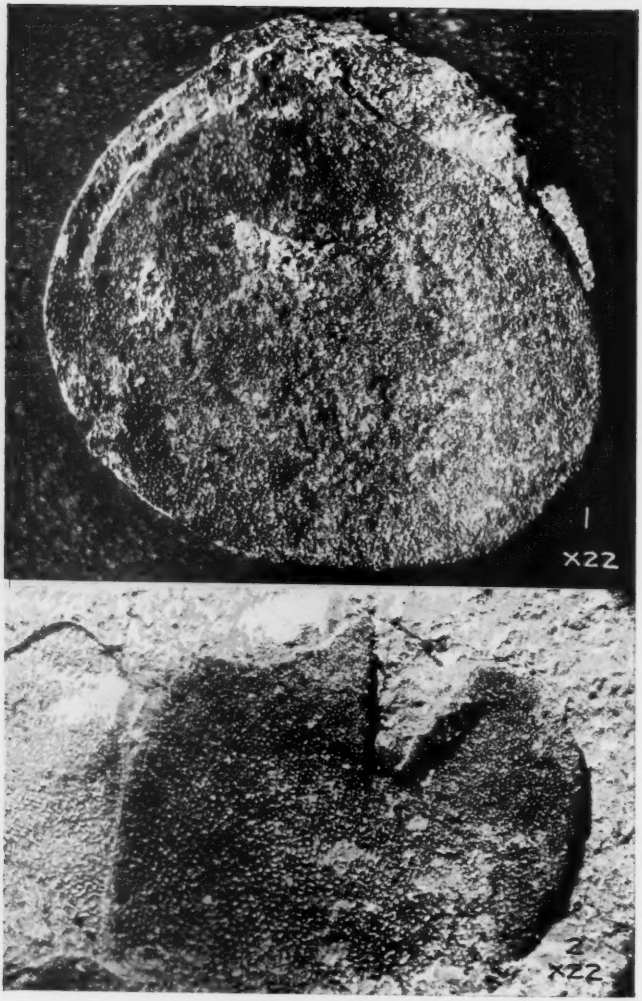

1
X22
2
X22

PLATE VIII.

Protosalvinia Ravenna, n. sp., D. W.

FIG. 1. Collapsed sporangium detached from matrix and photographed without treatment. Wrinkling seen in upper part and axial sinus faintly indicated to upper left of center. ×22.

FIG. 2. Axial depression, appearing V-shaped by accident of compression. Lateral lobes, with small thick-walled cells, seen on either side, grading into larger cells, in lower part of photograph. Portions of underlapping sporangia at left, and overlapping, at extreme lower left. ×22.

The convex surface of the epidermal cells decked with cutaneous waxy refractive matter, suggesting cobble-stone pavement, is well shown in lower part of figure.

Specimens from near base of Ohio shale at Ravenna, Ky.

to have been even more dominant as a source of petroleum than the easily recognized and abundant *Sporangites* spores or the *Protosalvinia* spore-containers. It is hoped that in the course of further study of these shales more may be learned as to the origin, structure, and composition of these more baffling plant residues. In this connection it is germane to mention a tentative conclusion reached by the late C. A. Davis in the course of his study of the oil shales of the Green River formation, on which he was engaged at the time of his death, namely, that an extremely delicately filamentous alga-like plant, growing in felt-like meshes to form carpet-like layers, most difficult of structural differentiation and identification, was perhaps the principal source of the oil in the shales of the Green River formation.

Besides adding two types to the list of plants preëminently adapted to the generation of petroleum in the Devonian shales, these studies furnish new criteria both for the micro-paleontological identification by the driller of a stage in the black shale series of the region and for the general purpose of stratigraphic correlation between regions. It is hoped that the success met in the micro-chemical treatment of the material in hand will stimulate a more widespread study of the thin and even minute carbonaceous plant residues so common in the rocks of the Devonian and other periods.

GEOLOGIC STAGE AND LOCALITIES OF THE FOSSILS.

The plants described as *Foerstia ohioensis* are found in great abundance in interbedded gray and blackish shales in the lower part of the Ohio shale in the bluff of a creek half a mile southwest of Vanceburg, Kentucky. This shale is of Upper Devonian age and has been referred to the Genesee. *Sporangites* is present in great numbers, but it is also widely distributed throughout the entire black shale group.

The specimens of *Protosalvinia Ravenna* here illustrated are from the gray and black shales overlying the limestone locally called Irvine "sand" (of probable Onondaga age) in the shaft

sunk for oil development on the hillside at Ravenna, 2 miles east of Irvine, Kentucky. These specimens bear the lot number 88-A. The same species are found in the railroad cuts along the river, 2 miles west of Irvine; in the lower part of the black shale and in the grayish layers immediately overlying the Irvine "sand" north of Junction City, Kentucky, and in the basal portion of the black shale in the quarries of the Devon Shale Oil Company on the north river bank, 2 miles northwest of Clay City, Kentucky. At all these localities the fossils are in the lower portion of the Ohio shale.

NOTES ON THE MICRO-CHEMICAL EXPERIMENTS.

On account of the differences in the functions of the plant parts and on account of the difference between the classes of the plants represented by the remains in hand, as well as on the basis of the mode of occurrence of the preservative secretions as cuticular surface coverings or as reinforcement of the walls of the subcutaneous cells, it was at the outset assumed that the special decay-resistant plant substances were probably allied in composition to the waxes or resin-wax group. Accordingly, reagents and solvents were for the most part used with this hypothesis in view. The following incomplete notes are preliminary, as further studies of this and other related materials are in progress.

In *Foerstia* all the specimens were opaque before treatment, as also were all but the thinnest fragments scaled from the sporangia of *Protosalvinia.* Both appear carbonized, especially *Protosalvinia.* Untreated *Foerstia* is more leathery in aspect and is, in fact, tougher and less subject to splitting when first gathered. *Protosalvinia* is wrinkled and looks more "dried out." It is important to note that none of the material responded to the solvents used (alcohol, ester, chloroform, carbon tetrachloride, carbon bisulphide, pyridine) even at boiling temperatures for considerable time unless the specimens had been previously treated with oxidizing reagents. However, *Protosalvinia,* after treatment three days with strong hydrofluoric acid at 50°–60° C., was

PLATE IX.

Protosalvinia Ravenna, n. sp., D. W.

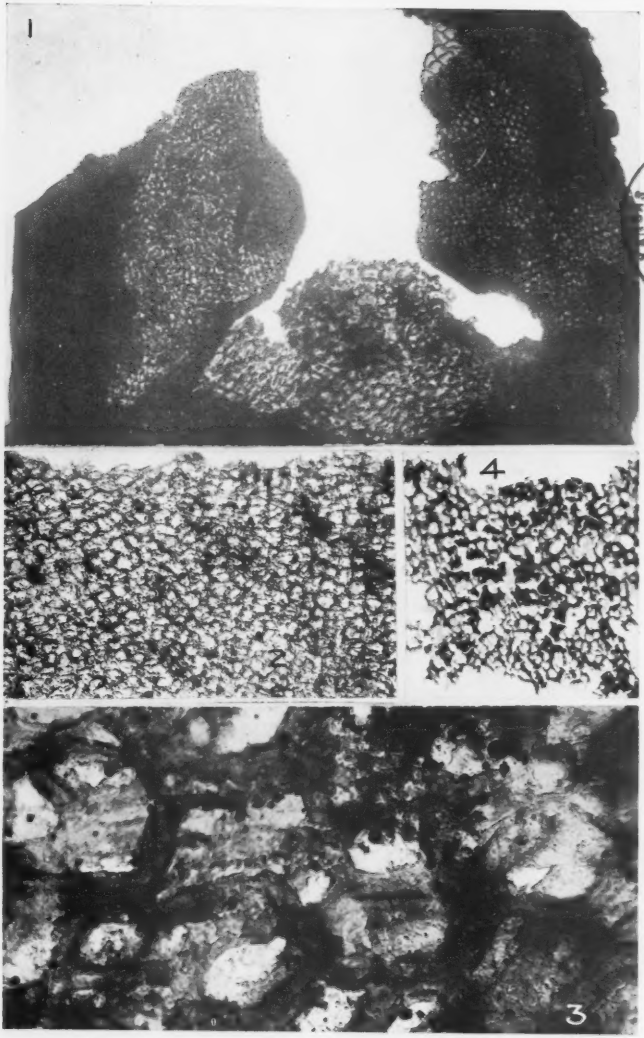
FIG. 1. Basal or axial portion of sporangium showing lateral cushions, "rings," in effect, with small cells on either side, and portion of wall with large cells on opposite side of spore sac. Treated in HFl and HNO_3 (50 per cent. + 50 per cent.) for 3 days at room temperature, followed by boiling 3 hours in pyridin. Portions of sporangium are still opaque, especially where both walls are cemented in contact. On upper right, below folded border, a thin strip has split off showing in single layer large outer cells of the opposite wall which projects beyond the broken edge of the smaller-celled, near wall of the lateral cushion. × 25.

FIG. 2. × 25, to show mesh of cells with walls thickened with russet-brown matter. Treated for 3 days in hydrofluoric acid at 50°–60° C., followed by KOH (50 per cent.) for 2 hours, which has removed most of the humic matter and has somewhat reduced the brown deposit. The cutaneous covering of straw-colored waxy matter appears as white patches seen through the subjacent brown-walled cells.

FIG. 3. Portion of Fig. 2, × 240, to show the russet-brown thickening of the lateral walls of the outer zone of cells, which are here seen to be at least 3 deep. The original cell laminæ are faintly seen, while the outer, cutaneous, waxy pavement shows white, as seen through the interiors of the cells of wall. The specimen represents the remains of one wall only of the sporangium.

FIG. 4. Fragment of sporangium wall, × 25. This specimen, after treatment with mixed hydrofluoric and nitric acid, was boiled for 10 minutes in alcohol which has dissolved and removed the lemon-yellow cutaneous or surface deposit, as well as a portion of the brownish cells of the underlying walls, the remains of which are here seen as a reticulate mesh. The white patches are openings where formerly lay the waxy cutaneous decking seen in Pl. VIII., Fig. 2.

From near base of the Ohio shale, Ravenna, Kentucky.



KANSAS STATE AGRICULTURAL COLLEGE
MAY 14 1923
LIBRARY

slightly attacked by alcohol, which, after boiling an hour, was stained a little at the expense of the brown matter. Similar slight staining resulted from the substitution of chloroform in place of alcohol. Practically no effect was noted when, after treating with HFl as above, *Protosalvinia* was subjected to KOH (50 per cent.) for two hours at room temperature. It is to be inferred, therefore, that the organic plant material has been "bituminized." Both in the clarification of the plant fragments and in the chemical experiments beneficial results were obtained from the use of hydrofluoric acid, which not only assists through removal of the inorganic matter, but seems also to exert a favorable influence on the reactions.

Solution in varying degrees, and with evident selective differentiation, was observed when, after preliminary treatment with HFl, the plant fragments were subjected either to HNO_3 or Schultz's reagent[3] before they were placed in the solvent. Schultz's reagent is the more drastic and rapid in its action. Both the nitric acid and Schultz's reagent are useful in rendering the specimens more transparent, probably due in part to the removal of "humic" matter, in advance of any application of solvents. In fact, portions of the specimens may be successfully studied under the microscope without further preparation. Neither of these two oxidants appears to attack the cutaneous yellow plant secretion, but the brown cell-wall thickening, when washed promptly, seems somewhat reduced as well as more translucent. After treatment for two days with HFl and HNO_3 in equal parts at 50°–60° C., *Foerstia* was found to have been more strongly affected than *Protosalvinia*. Similar specimens, treated as above, or with Schultz's reagent following HFl, for the same period, were energetically, and almost instantly, attacked by a 2 per cent. solution of KOH, which rapidly darkened while the brown matter was wholly removed as is illustrated in Fig. 4, Plate VI, with slight effect on the yellow matter, though with prolonged subjection to KOH the yellow deposit also eventually disappears. The cell remains are much swollen in the caustic potash prior to dehydration.

[3] 10 HNO_3 (1 : 1) and 3 $KClO_3$.

Some results of the action of solvents may be briefly noted. The action of solvents on specimens of *Foerstia,* which, in each instance had first been treated with HFl for two days, followed by two days on Schultz's reagent, all at 50°–60° C., is as follows: Boiled in C_2H_5OH for 1 hour, the brown matter and the yellow are somewhat reduced and the cells dilated. Boiled in $CHCl_3$, reduction of brown and yellow matter is noted. Carbon bisulphide and CCl_4 applied at boiling temperatures for 1 hour do not have visible action on *Foerstia.* After subjection to pyridine at 100° for an hour, the yellow matter is taken out and the brown is shrunken and generally darker, as shown in Fig. 3, Plate VI.

Sporangia of *Protosalvinia,* after treatment with HFl and HNO_3 in equal parts, at 50°–60° C. for 3 days, were submitted to solvents with the following results: CS_2 for an hour, and CCl_4 for two days, at boiling temperature, had no visible effect, thus agreeing with the tests of *Foerstia.* Boiling in alcohol 10 minutes removes the yellow matter, while the brown, much shrunken, appears grayish, losing its warm red tone. Pyridine even for 3 hours at the boiling point does not act so strongly on *Protosalvinia* as on *Foerstia,* and is limited to some reduction of the yellow in the thinnest parts, while ester appears to cause both reduction of the yellow and the brown matter and swelling.

The foregoing experiments clearly show that both in *Foerstia* and in *Protosalvinia* the brown preservative material of the cell walls differs chemically, as well as optically, from the yellow surface decking. The experiments are interpreted as indicating also not only that the brown matter of the one differs chemically somewhat from that of the other, but that the yellow cutaneous deposit differs in the two plants. Thus, boiling in alcohol removes the yellow matter from oxidized *Protosalvinia* within 10 minutes, while in *Foerstia* after an hour the yellow substance is changed but slightly. Pyridin, which removes the yellow in *Foerstia,* has not so strong an effect on *Protosalvinia.* This accords with the natural assumptions based upon biological probabilities, since it is practically certain that neither the brown decay-resistant substance of the thickening of the cell walls, nor the yellow cuticular

surficial deposit of the alga, had the same original chemical composition as the similarly deposited brown and yellow secretions of the sporangium wall of a much higher order of plants, possibly related to the Lycopods. The results of the experiments already made indicate compositions in the yellow more nearly related to the waxes, while the brown deposits on the walls of the subcutaneous cells may be presumed to represent compounds somewhat resinous or waxy-resinous in nature. The brown material in *Foerstia* probably has its closely related plant product in some of the living algæ from which it presumably differs in composition to correspond to its greater resistance to decay.

Mother Sources of Oil in the Black Shales.

The results of this examination show that, in addition to the resinous or waxy-resinous spore exines of different species known as *Sporangites* that occur so widespread and locally in innumerable numbers in the black shales of the Devonian and basal Mississippian, we have at least two types of larger and more complex plant growth locally in the greatest abundance that, according to the micro-chemical indications, are especially suited to serve as ideal mother substances from which to generate artificial petroleum of high grade, and that beyond reasonable question have been important contributors to natural Appalachian oils. The chemical tests in progress by the junior author, though incomplete, are sufficient to show a variation in the composition of these plant substances that may be as important in determining the character of the oils as they are interesting to the paleontologist and stratigrapher. Obviously in these remains of plants of different orders we have vast amounts of somewhat bituminized and characteristically highly hydrogenous plant material, which probably varies also both in fusing temperatures and in temperatures of distillation. It is reasonable, therefore, to conclude that the detailed micro-chemical and micro-thermal study of these fossil remains will throw great light, not only upon the origin of petroleum in general in the Devonian of the Appalachian trough, but

upon the original sources—*i.e.*, the fossil plant products and remains responsible for the different characters and qualities of the distillates initially. These ingredient products, by their different compositions and properties, should account also, to some extent at least, not only for the variation in the distillates obtained in the same retort and under identical treatment from different shales, but also for the varying temperatures at which the same rocks give distillations of different types.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

MAGNETITE PEGMATITES OF NORTHERN MINNESOTA.[1]

F. F. GROUT.

In northern St. Louis County, Minnesota, there is a great granite batholith (Fig. 48). Scattered here and there across the batholith area are some small magnetite deposits. Most of them would probably pass unnoticed except that they are not far north of the series of productive iron ranges of Minnesota. As it is, considerable exploration has been carried on and the price of lands showing magnetite has been remarkably increased. In 1919 the Minnesota Geological Survey assigned the writer first to an examination of the prospects and later to a study of the whole district.[2]

GENERAL GEOLOGY.

The Vermilion Granite and Its Relations.[3]—The granite batholith intrudes chiefly mica schists, but smaller amounts of hornblende schist and gneisses occur locally. The hornblende schists grade into Ely (Keewatin) greenstone and since the mica schists are more abundant they are assigned to the widespread Knife Lake slate (Lower-Middle Huronian) formation of the Vermilion district, rather than to the less important Coutchiching schists, though some small amounts of mica schist may be older than the Ely greenstone. No sign of the Soudan iron-bearing formation has been found in the contact rocks of the granite.

The granite clearly intrudes the schists assigned to the Hu-

[1] Published by permission of the Director of the Minnesota Geological Survey. Presented before the Society of Economic Geologists, Ann Arbor Meeting, December, 1922.

[2] Report nearly ready for the press.

[3] The granite was shown in early maps by N. H. Winchell; see Minnesota Geol. and Nat. Hist. Surv. Final Report, vol. 4, Plate 67, 1899. This map shows mica schist next to granite, which was ignored in the later work of the U. S. Geol. Survey, Mon. 45, though the latter shows in much more detail the division of Archean and Huronian formations.

ronian and is therefore supposed to be Algomian in age. This agrees with its fresh appearance in contrast with the gneissic Laurentian granite of this and neighboring districts. It is pro-

FIG. 48. Sketch map of main geologic divisions of St. Louis County, Minn., and adjoining areas. Spots indicate magnetite areas in the granite batholith. Crosses indicate the four best magnetite pegmatites.

posed to name the formation Vermilion granite from the good exposures on Vermilion Lake and along the Vermilion River, which flows almost across the center of the area.[4]

Erosion has exposed the main batholith and some satellites to

[4] The formation name Vermilion was once used by the geologists of the Minnesota Survey for the series of schists in this county; but when they found the contact rocks were altered phases of several different formations they gave up the usage; the term is available for use in this new way.

various depths. A belt about 6 miles wide, roughly east and west across the county, shows almost uniform massive granite, but a much larger area is confused by innumerable inclusions and pegmatitic and aplitic dikes; in short by all the variety characteristic of the roof phases of batholiths. In fact some of the included schist areas are to be classed as roof pendants rather than fragments.

The Vermilion granite is predominantly a biotite granite with light pink color. It has locally along the south side a basic border phase. Over most of the granite area, the numerous inclusions of mica schist may have slightly modified its character as they were partly assimilated, but the effect on the granite does not appear to have been important. Biotite, normally about 2 per cent., may rise locally to 10 per cent.; it is commonly brown but is green in a few specimens. The feldspars of the granite are orthoclase; a plagioclase that varies in places from albite to oligoclase; and in most places abundant microcline.

Pegmatites.—Pegmatite occurs as occasional segregations and numerous dikes. These are most numerous in the roof phases,

FIG. 49. Net or stockwork of pegmatite dikes in mica schist, 2 miles west of Ray, Minnesota.

so that in a large way they constitute the matrix of a schist breccia. A few more regular dikes extend out into the schist.

North of the granite some dikes follow approximately the schistose structure and outcrop as great ridges 40 or 50 feet wide; but these large dikes have not been found to contain magnetite. The more abundant magnetite-bearing dikes in the roof phase have a pink color, and cross the earlier structures at high angles.

The chief minerals of the pegmatite are pink microcline, or its graphic intergrowths with quartz, white to greenish albite (or oligoclase), and quartz. Biotite is the chief dark mineral but there are locally magnetite, muscovite, garnet, and tourmaline, and commonly all dark minerals are absent. Quartz varies up to 95 per cent., but in the average pegmatite is probably less than 20 per cent.

The texture of the pegmatites shows the usual variation, and aplites are associated in many places, even occurring in the same dike in rudely banded structures.

MAGNETITE DEPOSITS.

Distribution.—While it can not be assumed that the parties of the Survey saw all the magnetite of this large area, they have visited and mapped with care all the properties of the main prospecting companies; and all properties where there were rumors or reports of ore; they also discovered many deposits of which the settlers and prospectors seemed unaware.

In the map, Fig. 48, spots are placed to show where magnetite has been seen, and a few of the richer deposits are indicated by crosses. The formation can hardly be classed as an "iron range," either topographically or in the sense of an extended belt like other Lake Superior ranges.[5] The magnetite occurs scattered widely over the area of the Vermilion granite, and the occurrences of the two coincide so closely that some genetic relation between them is not to be doubted. Magnetite occurs in a few places in the normal granite,—a few pounds might be selected containing 10 per cent. magnetite,—but all the more notable concentrations are in pegmatite. A few localities show-

[5] The most active promoter of the prospects in recent years called his properties the Namekan range.

ing considerable magnetite are tabulated on page 263, with estimates of their iron content.

Rocks Associated.—Magnetite occurs in pink pegmatites, of a late stage of igneous action in the roof phases of the granite batholith. The roof phase is commonly a shattered mass of mica schist with nearly equal amounts of schist and intrusive. Magnetite is much more common in this mixture than in masses where either rock is largely predominant.

Minor amounts of magnetite in small stringers may be found related to a highly siliceous phase of pegmatite—a silexite; or to an especially sodic (albite) phase. The only masses constituting more than a few pounds, however, are the pegmatites already described.

Mineral Associates.—Magnetite occurs chiefly as a primary mineral in some of the pegmatites. It appears to have formed early in the series of minerals, but shows very imperfect crystal forms. Its most intimate associate is biotite. In some pegmatite, biotite occurs alone, in others magnetite alone, but most of the magnetite has biotite either as a border fringe or as included plates, or both.

Forms and Structures.—The magnetite deposits, considered in a large way as material that might be mined, are probably to be classed as "stock-works." (See Fig. 50.) The magnetite is in a network of veins or dikes in shattered schist and granite, striking in all directions and curving in and out around numerous inclusions of the wall. Some dikes follow the schistose structure, but rather more of the ore-bearing dikes cross the structure at high angles. Most of the ore-bearing dikes have sharply defined walls, but grade along their length into lean pegmatite or granite. Many are so small and irregular that they are to be classed as stringers rather than dikes. The dikes in contact with schist have in places injected the schist lit-par-lit, but only rarely has any magnetite been seen in the schist or smaller injections. Some magnetite-pegmatite occurs in segregations up to three feet in diameter in granite.

The network of dikes bearing magnetite is in a few places

extended into a belt, constituting a roof phase of the granite, between more massive granite and the earlier schist. Such belts may extend more or less continuously for some miles. No such belt, however, is continuously exposed. The scattered outcrops at Kinmount and for a few miles east strongly suggest such a belt with schist on the south and granite on the north. Magnetite occurs in a belt about 100 paces wide.

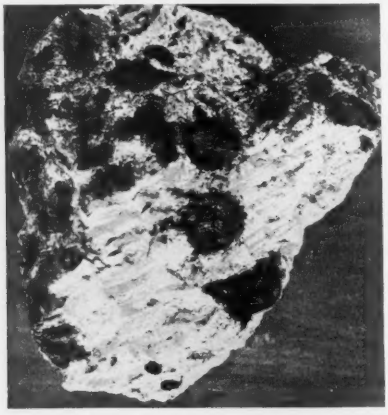


FIG. 50. Magnetite bearing pegmatite, St. Louis County, Minnesota, About ½ natural size.

As a rule the magnetite occurs in the pegmatites as scattered grains among other minerals, without regularity (Fig. 50). A number of pegmatite dikes show some banding of minerals, or differentiation; such as a band of quartz in the center and more feldspathic material at the sides; or bands of alternating aplite and pegmatite. These structures are more common in the older pegmatites than in the late ore-bearing pegmatites, but banding of constituents occurs in some of the ore also. (See Fig. 51.) When magnetite forms a band parallel to the sides of a dike or sheet, it has not apparently formed as a crustified banded vein; for no case of symmetrical banding by magnetite has been dis-

covered. In a few cases magnetite grains are especially abundant in a pegmatite along the borders of a schist inclusion. The aplitic dikes and phases of dikes have nowhere been found to contain more than 2 per cent. magnetite.

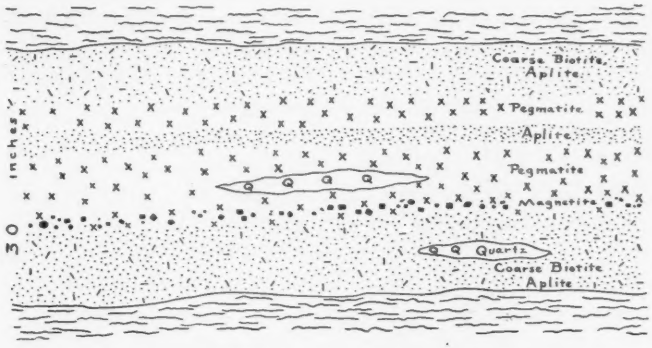


FIG. 51. Banded dike of magnetite pegmatite and aplite.

Where the pegmatite is coarse grained, the magnetite is also coarse. Grains of magnetite two or three inches across are readily available and have stimulated a great deal of interest in the prospects.

Extent of Magnetite-Pegmatite Bodies in Depth.—No prediction can be made ahead of actual exploration of the extent or form of such an ore body as a hill of schist, shot through with irregular dikes of magnetite pegmatite. Several of the areas, however, have a slight elongation in one direction, as if a belt or tabular mass was to be indicated. It may be suggested, where granite appears to dominate on one side and schist on the other side of the prospect, that the deposit is in a roof phase of the batholith; the schist representing a roof pendant. The magnetite rock mixture in such a case might be expected to follow around the contact of the two. The suggestion, however, has not made it possible to find or trace any ore bodies. It is simply to be noted that most of the good magnetite is in a mixed rock;

other mixed rocks with apparently as favorable conditions are wholly barren.

In such a deposit, bordering on a roof pendant, the linear extent of the prospects on the surface may give the only clue available as to the depth of the magnetite bodies. It would be a liberal estimate (until drilling reveals facts) to assume that the rock is equally rich in iron to a depth as great as the length of its surface outcrop. The inaccurate records of past drilling offer no reason for modifying such an estimate. Some magnetite was no doubt found at a depth of several hundred feet.

Chemical and Assay Data.—The pegmatite is too variable to afford wholly satisfactory samples for analysis. A general average of the magnetite-bearing rock from the dump of a deep shaft in Sec. 3, T. 66 N., R. 17 W., was analyzed by the writer with the following results. An analysis of the granite of the main batholith is added for comparison.

It is noteworthy that the ratio of soda to potash is no greater

		I.	II.
Silica	SiO_2	58.72	72.06
Alumina	Al_2O_3	10.81	16.00
Ferric oxide	Fe_2O_3	12.84	.45
Ferrous oxide	FeO	6.80	.72
Magnesia	MgO	.94	.97
Lime	CaO	.82	.86
Soda	Na_2O	3.59	4.56
Potash	K_2O	4.89	3.45
Combined water	H_2O+	.34	.39
Moisture	H_2O-	.16	.05
Titanium oxide	TiO_2	.42	.12
Zirconia	ZrO_2	.02	.03
Phosphorus oxide	P_2O_5	.20	.09
Pyrite	FeS_2	trace	.09
Chromium oxide	Cr_2O_3	none	.02
Manganese oxide	MnO	.08	.06
Strontia	SrO	none	none
Baryta	BaO	.07	.12
		100.70	100.24

I. Magnetite pegmatite selected from dump of shaft in Sec. 3, T. 66. N., R. 17 W., Minnesota.

II. Biotite Granite, Northern St. Louis County, Minnesota. This seems to be the "parent" rock of the pegmatite number I.

in the pegmatite iron ores than in the granite from which the pegmatites probably were derived.[6]

A private report made by Charles Rees to Mr. Grenager of Duluth quotes an analysis of selected magnetite from the property in Section 3, T. 66 N., R. 17 W., as follows:

	Per Cent.
Iron	68.25
Sulphur	.055
Phosphorus	.025
Titanium	1.60

Samples taken by the Survey parties and tested by the Minnesota School of Mines Experiment Station show the low iron content of the outcrops as a whole.

Survey No.	Location.	Soluble Iron, Per Cent.	Magnetic Iron,[7] Per Cent.	Phosphorus, Per Cent.
2337A....	Ash River	2.44	1.54	n.d.
2367X...	Kinmount (estimated average)	4.80	3.80	n.d.
2381	Kinmount (selected)	10.80	9.60	.101
2410.....	Sec. 29 Ash River (selected)	17.13	15.81	.095
2369.....	Sec. 3–66–17 (ore dikes)	9.34	8.11	.082
2370.....	Sec. 3–66–17 (gangue, etc.)	4.55	.26	.101

Sample 2367X contained 0.23 per cent. titanium oxide; the concentrate derived from it had 0.35 per cent.

The concentration tests given below are also significant of the chemical nature of the ore. The quality of the concentrate is so fine that a premium is offered in the market. The iron is high and phosphorus very low. The average of three good deposits shows .006 per cent. phosphorus in the concentrate at 100 mesh. The titanium is not high enough to be objectionable.

Magnetism.—The ore in hand specimens affects the compass very notably. It was hoped for a time that the ore bodies could be found and traced underground by their effects on the dip needle and dial compass. After detailed work in several prop-

[6] Washington, H. S., "The Correlation of Potassium and Magnesium, Sodium and Iron, in Igneous Rocks," *Proc. Nat. Acad. Sci.*, vol. 1, p. 574 (1915).

[7] Magnetic iron is iron in such mineral forms that it can be concentrated magnetically.

erties it was found that the effects are slight and erratic. While some abnormal dip and dial readings occur in the same forty acres with the ore, the richest outcrops did not always give the abnormal readings; and some abnormal readings were obtained on bare granite outcrops. The correlation is very rough, to say the least. No belt could be followed magnetically, to indicate an extension of the deposits underground.

The magnetism of the ore is amply sufficient, however, for purposes of concentration. In 1919, about 1,100 pounds of ore was sent from Sec. 3, T. 66 N., R. 17 W., to the Minnesota School of Mines Experiment Station for mill test. The whole sample contained 35.80 per cent. iron. Half a ton was magnetically concentrated at several stages of grinding.

One-inch feed

	Concentrates	Middlings	Tailings
By weight	47.58%	25.50%	26.92%
Iron	60.91	24.32	2.30
Silica	9.96		
Phosphorus ...	.006		
Titanium	2.72		

Middlings crushed to ½ inch

	Concentrates	Middlings	Tailings
By weight	8.37%	6.17%	10.97%
Iron	60.83	13.78	2.37

Middlings crushed to 4 mesh and 10 mesh gave small concentrates containing about 50 per cent. iron. Without crushing finer than half-inch size, nearly all the iron gets into the concentrates.

SUMMARY OF MAGNETIC SEPARATION TEST.

	% by Weight.	% Iron.	% Silica.	% Phosphorus.	% Titanium.
Feed	100.00	35.80	....	....	....
Total concentrate	57.21	60.73	9.72	.010	2.61
Total tailings	42.79	2.48	....	....	....

Size and Quality of the Magnetite Prospects.—Any discussion of the tonnage of such a deposit must be made with a clear understanding of the conditions stated above,—the admixture of barren schist, and an erratic concentration in an erratic rock. But with all these handicaps, the showing of magnetite has been sufficient in several places to stimulate expensive prospecting. The Survey parties have therefore taken a number of careful samples and made detailed maps of several areas. The geologists made estimates of the per cent. of magnetite in the several outcrops, and their estimates have been checked by assays.

It is easily possible in several places to pick out a few pounds of magnetite that will assay about 70 per cent. iron. These can not be considered ore, however. Samples of half a ton can easily be selected from prospect holes, or with a small amount of blasting, which will assay 35 per cent. iron. A dome-like hill of 40 acres area and perhaps 150 feet height may possibly be found to assay 10 per cent. iron, though none better than 5 per cent. have been sampled or seen by the Survey parties. The most noteworthy areas are shown in the table below, with the per cent. of iron estimated from surface outcrops by men of long experience in magnetite ores. In some, separate estimates were made of the richness of the pegmatite and its amount in the outcrop, and the estimates were checked by assays. These are the best estimates available at the present time, since the drill cores, used for promoting, have been made useless for accurate estimates of quality and quantity.

TABLE OF AREAS AND ROUGHLY ESTIMATED PER CENT. OF "MAGNETIC IRON" OF THE BETTER-LOOKING EXPOSURES IN NORTHERN ST. LOUIS COUNTY.

Location	Area, Acres	Magnetic Iron. Per Cent.
Sec. 3, T. 66 N., R. 17 W.	10	5
Sec. 4, T. 66 N., R. 17 W.	20	4
Sec. 29, T. 68 N., R. 19 W.	10	10
Sec. 29, T. 68 N., R. 19 W.	40	5
Sec. 32, T. 68 N., R. 19 W.	40	4
Sec. 15, 16, 17 +, T. 67 N., R. 20 W. ..	100	5
Sec. 33, T. 67 N., R. 17 W.	20	5
Sec. 36, T. 66 N., R. 17 W.	10	5

ORIGIN OF THE MAGNETITE BODIES.

The first and most evident fact is that these magnetites are primary minerals of the pegmatites related to the Vermilion granite. Beyond this, few suggestions can be made.[8]

Second, the granite itself has in several places some magnetite, showing that the magma was not an improbable source for the derivation of iron-bearing differentiates.

The third evident fact is that the magnetite-bearing pegmatites are most notably developed in a zone of fragments and inclusions between massive granite and large bodies of metamorphic rocks. It can not be maintained, however, that the nature of the older rock of the fragments and roof of the batholith had any essential part in the origin of the ore. The pegmatites may be rich in one place and lean in another with similar schist in similar relations. And the magnetite concentrations are partly in mica schist and partly in hornblendite areas, though the two rocks differ widely in their iron content: about 5 per cent. in the mica schist, and about 10 per cent. in the hornblendite. This is most clearly shown north of the falls of Ash River where an area of practically continuous (though very lean) magnetite rock covers perhaps 80 acres. The southwestern half shows mica schist with less than 5 per cent. hornblende schist; the northeastern half shows, on the contrary, practically no rock but hornblende schist and magnetitic pegmatite. The magnetite in the pegmatite, therefore, seems to be a result of processes inherent in the granite and not of processes of assimilation of the country or roof rock.

This point may require further discussion. The similar pegmatitic magnetites of the eastern United States have been attributed to the iron of the silicates in the older rocks.[9] The arguments there used do not fit the Minnesota conditions. Certain features of the Minnesota rocks, however, do suggest a good deal of

[8] Winchell, H. V., once suggested that iron formations may have been included in material melted up to form the granite but he probably would not maintain the idea now. See "Geologic Age of the Saganaga Granite," *Am. Jour. Sci.*, vol. 41, p. 390, 1891.

[9] Miller, W. J., "Magnetic Iron Ores of Clinton County, New York," ECON. GEOL., vol. 14, p. 509, 1919.

reaction between the igneous rock and its walls or roof. Most of the walls are biotite schist, about 30 per cent. biotite; and it was noted in the description of the granite that where schist is abundant the granite seems unusually biotitic; biotite increasing from 2 per cent. to 6 or 8 per cent., as if it had been absorbed and crystallized out again, becoming indistinguishable from primary biotite. The case is equally clear for the assimilation of some biotite in the pegmatites; the biotite, spalled off from inclusions of biotite schist, is recrystallized so thoroughly as to become indistinguishable from primary biotite in the pegmatite. Now the increase in biotite content by assimilation is evidence of the increase in iron content, and might strongly suggest that magnetite was also a result of assimilation. The two minerals occur in similar relations to pegmatite—they even occur together in a number of cases. Two other facts, however, seem to be opposed to any such theory of the origin of the magnetite: the mica schists show no trace of magnetite, and the alteration of the schist inclusions does not seem to have produced magnetite in any of them.

It is therefore believed that the iron was first concentrated from a granite low in iron, into the pegmatites by the segregation of those pegmatites; and locally concentrated in some of the late pegmatites (rather uniformly in all), near the upper phase of the batholith where the schistose roof was shattered and broken. The conditions which determined that magnetite developed in some pegmatites and not in others may have been accidental, but are so far unknown.

COMPARISON WITH DISTRICTS HAVING SIMILAR ORES.

Lyon Mountain, New York, produces magnetite from a series of pre-Cambrian pegmatite dikes, intruding gabbro and amphibolite. Miller concludes[10] from the constant association that the pegmatites derived much of their iron from the gabbro and amphibolite. The normal granite of Lyon Mountain contains

[10] Miller, W. J., "Magnetic Iron Ores of Clinton County, New York," ECON. GEOL., vol. 14, pp. 509–535, 1919.

from one to three per cent. magnetite, and the gabbro much more. Both are therefore richer in iron than the country rocks in St. Louis County, Minnesota. Relatively little concentration was necessary in the magma to make the Lyon Mountain ore. The magnetite pegmatites are mineralogically similar to those in Minnesota, but are larger and form much more continuous belts than have been discovered in Minnesota.

Magnetite ores in the Highlands of New Jersey are partly in pre-Cambrian pegmatite. Bayley concludes[11] that after the cooling of the granite (gneiss), which had little magnetite, a more ferruginous portion of the magma intruded the gneiss as magnetite pegmatite; and still later the iron-bearing solutions emanating from deep magmatic sources enriched the ore somewhat. In this later enrichment the New Jersey pegmatites seem to differ from those in Minnesota. No vein-like masses seem to cross the Minnesota ores except a few small sulphide veinlets. Much more of the New Jersey magnetite ore is outside the pegmatite in the country rocks than is in the pegmatite. In this respect no comparable deposits are found in Minnesota.

In North Carolina occur pre-Cambrian magnetite pegmatites which Bayley[12] finds closely similar to those in New Jersey. The main ore is a magnetite-hornblende rock with or without quartz and epidote; but this is crossed and in places enriched by dikes of pegmatite, magnetite pegmatite, and even pure magnetite.

Outside of the Appalachian Mountain region few magnetite deposits have been described as being so definitely related to pegmatite. Ball has described a deposit of lean iron ore closely resembling the Minnesota deposits, from the pegmatites of the Georgetown quadrangle, Colorado.[13] Van Hise and Leith mention briefly, also, a deposit in the Atikokan district of the Lake

11 Bayley, W. S., "Iron Mines and Mining in New Jersey," New Jersey Geol. Survey, vol. VII., Final Rept., pp. 147–193, 1910.

12 Bayley, W. S., "Magnetic Ores of North Carolina—Their Origin," Econ. Geol., vol. 16, pp. 142–152, 1921.

13 Ball, S. H., "General Geology of the Georgetown Quadrangle." In U. S. Geol. Survey, Prof. Paper 63, pp. 61–63, 1908.

V 18/3 APR/MY 23 UMI

Superior region [14] which seems pegmatitic, but consists largely of amphibole and magnetite, related to a diorite, thus differing greatly from the pegmatites here described.

The other magnetite ores of Minnesota are of very different origin. Those in the Soudan formation of the Vermilion range and those actively worked on the east end of the Mesabi range are altered sedimentary beds, not at all like pegmatites in texture or occurrence.

ECONOMIC CONSIDERATIONS.

Most of the prospects that were seen are outcrops on hill sides where quarries could be started with economical mining methods. These may be expected to furnish material from open cuts to a depth of 200 feet or more if they prove commercially profitable.

The massive, little-jointed granite and metamorphic rocks are hard rocks to drill and excavate, but no harder than the taconite of the Mesabi range. A more serious limitation is that due to narrowness of the belts of richer material which might make the quarry of inconvenient shape for work.

Railroads now pass close to some prospects, but all lie 20 to 50 miles north of the producing ranges of the state, so that the freight haul would be noticeably greater.

In a formation so erratic as a local magnetite concentration in a group of pegmatite dikes irregularly intruding and including a folded schist, reliable exploration is very costly. Drill holes must be closely spaced before it is safe to assume that they represent intervening rock masses. Practically no ore can be safely assumed beyond the limits of the last drill hole or exposure. Magnetic surveys were made by the parties of the Geological Survey but, in our judgment, this method of prospecting pegmatites is practically useless.

The coarse grain and magnetism of the ore make it possible to mill out a high-grade concentrate very cheaply. With coarse crushing the ore would yield a salable concentrate, a middling, and salable tailing (crushed rock). Only the middlings would

[14] Van Hise, C. R., and Leith, C. K., "Geology of the Lake Superior Region," U. S. Geol. Survey, Mon. 52, p. 562, 1911.

require finer crushing; and even that does not need to be very fine to give up most of the iron as a rich product. The process would not require elaborate or special machinery. Little of the concentrate would require sintering.

"In general it may be said that the profit per ton that may be made by the treatment of low-grade iron ores will be small, and only by handling large tonnages can large profits be made."[15] After drilling has shown the quality and quantity of ore more accurately than they can be estimated from surface exposures, careful calculations of costs and selling prices are needed before further expenditures are justified.

Summary of the Possible Use of the Magnetites.

Magnetite ores of a rather different type from pegmatites are now being developed along the east end of the Mesabi range. In comparison with those ores the magnetites of the pegmatites have the following advantages and disadvantages:

The pegmatites are much coarser and simpler to mill.

They are much smaller and the several known prospects are many miles apart.

They have 5 to 10 per cent. iron, instead of 25 to 30 per cent. iron.

They are farther from the docks for Lake shipment.

They are less thoroughly jointed.

Their exploration must be more careful and more expensive.

University of Minnesota,
Minneapolis, Minn.

DISCUSSION.

W. J. Miller: I am interested in Mr. Grout's paper because I have made a study of magnetic iron ores in part of northern New York where some of the conditions are the same, and other conditions are different. Mr. Grout has mica schists with some hornblende schist. In New York the mica schists are not usually associated with the ore. There are hornblende schists which, I am almost certain, are meta-gabbro, and these are intricately cut by highly pegmatized granite.

Ore occurs in association with meta-gabbro in highly pegmatized zones

[15] Davis, E. W., Minn. School of Mines Exp. Sta. Bull. 9, p. 135, 1921.

in granite. There are also later pegmatites. From your description they appear to be exactly the same as your pegmatites. In vicinity of Lyon Mountain, several hills have been burnt over and show pegmatites cutting right across pegmatized granite zones. They are distinctly later pegmatites, and I have not attempted to suggest that magnetites in pegmatites of later origin are any more than ordinary deposits. There is a constant association of meta-gabbro (hornblende schist) with the ore zones, and I have recently published a discussion on that relationship. My contention has been that the iron has been largely derived by pegmatitic granite solutions from the old meta-gabbro which is exceedingly rich in iron.

Another question. You say there are a few zones rather straight, and richer in magnetite, parallel with the roof pendants of mica schists. Why are they here? Biotite schist is somewhat rich in iron. Does not this suggest the possibility of the derivation of the ore from the schist?

Mr. Grout: I took it entirely as a matter of structure that the pegmatite occurred chiefly in that border zone of granite, next to the roof pendants of mica schists. Such pegmatites with mica schists do not occur near the central deeper granite. Mica schists show about 5 per cent. of metallic iron. Hornblende schists 10 to 15 per cent. I selected four areas as best, and two of best show hornblende as well as mica schists. In one particular case, there is an area of 80 acres covered with schist fragments, with magnetite pegmatite intruding them. It is a typical case where magnetite runs about 2 per cent. over the 80 acres. Forty acres of it show almost wholly hornblende schist inclusions, and the other forty, mica schist inclusions. Certainly on the surface there was no more richness of magnetite among hornblende inclusions than biotite.

CHALMERSITE AT FIERRO, NEW MEXICO, WITH A NOTE ON ITS OCCURRENCE AT PARRY SOUND, ONTARIO.

G. M. SCHWARTZ.

INTRODUCTION.

THE examination of polished surfaces of ores from Fierro in the Hanover district of New Mexico revealed the presence of chalmersite ($CuFe_2S_3$) a hitherto little known and rare mineral. The importance of the mineral in the concentration of the Fierro ores, and the fact that but two regions have supplied the specimens thus far described, led to a detailed study of the available material. The data presented are based on a set of twenty specimens which were selected at random from a lot of ore from the Republic mine at Fierro.

I am indebted to Messrs. E. W. Davis and H. H. Wade of the Minnesota School of Mines Experiment Station for information regarding tests, and for analyses; also to Dr. W. H. Emmons and Mr. G. A. Thiel for suggestions and criticism.

PREVIOUSLY KNOWN DATA ON CHALMERSITE.

Chalmersite, from the Morro Velho mine, Brazil, was originally described by Hussak.[1] Further data on material from the same locality has been given by Rinne[2] and Palache.[3] Its occurrence on Prince William Sound, Alaska, was originally noted by Capps and Johnson[4] and was more fully described by Johnson.[5]

[1] Hussak, E., "Ueber Chalmersit, etc.," *Centralb. für Mineralogie,* pp. 69–71, 1902; also pp. 322–333, 1906.

[2] Rinne, F., *Centralb. für Mineralogie,* p. 207, 1902.

[3] Palache, C., "Mineralogical Notes," *Am. Jour. Sci.,* vol. 24, p. 255, 1907.

[4] Capps, S. R., and Johnson, B. L., "Mineral Deposits of the Ellmar District," U. S. Geol. Survey Bull. 542, pp. 101–120, 1913.

[5] Johnson, B. L., "Preliminary Note on the Occurrence of Chalmersite in the Ore Deposits of Prince William Sound, Alaska," ECON. GEOL., vol. 12, pp. 519–525, 1917.

Chalmersite crystallizes in the orthorhombic system, has a pale yellow or bronze color resembling pyrrhotite or millerite. It is strongly but variably magnetic. Its hardness is 3.5, and specific gravity 4.03. The composition is $CuFe_2S_3$, as shown by Palache and Johnson. It may also be written $Cu_2S.Fe_4S_5$, to show its relationship with chalcocite and pyrrhotite. Its appearance and reactions on the polished surface are given by Murdoch and by Davy and Farnham in their tables for identification of ore minerals on polished surfaces. The fact that it occurs with pyrrhotite which it closely resembles, especially on polished surfaces, makes its identification difficult. It was found, however, that a saturated solution of KOH tarnishes pyrrhotite to iridescence, while chalmersite remains untouched. This made the study of rather minute textures possible.

Analyses are given by Dana [6] and Johnson.[7] Johnson showed that the chalmersite from Prince William Sound contained very nearly the theoretical percentages of $CuFe_2S_3$, which are Cu = 23.42, Fe = 41.14, S = 34.44.

The chalmersite of Brazil occurs as crystals associated with chalcopyrite and dolomite on limonite derived from the alteration of pyrrhotite. The Morro Velho is a gold mine but the minerals found besides chalmersite include siderite, dolomite, calcite, quartz, albite, apatite, arsenopyrite, pyrite, chalcopyrite, magnetite. It is apparently a vein of the deep zone type.

In Alaska chalmersite occurs as a massive mineral associated with chalcopyrite, arsenopyrite, pyrrhotite, sphalerite, galena, gold and silver, in veins along sheared zones in greenstone. This occurrence is also a product of the deep zone type.

CHALMERSITE AT PARRY SOUND, ONTARIO.

Chalmersite has recently been identified by Copeland [8] in a polished specimen from the deposits at Parry Sound, Ontario, which are believed to have been formed in the deep vein zone.

[6] Dana, J. D., "System of Mineralogy," Appendix II., p. 27.

[7] Johnson, B. L., *op. cit.*, p. 521.

[8] Copeland, W. A., unpublished thesis, University of Minnesota, 1920.

The writer has compared Copeland's specimen with chalmersite from Prince William Sound and Fierro, and checks his identification. In fact the intergrowths of chalmersite and chalcopyrite at Parry Sound and Fierro are almost identical in some cases, as may be seen by comparing Plate X., *C* and *D*.

The Parry Sound specimen contains pyrrhotite, chalcopyrite, chalmersite, magnetite, sphalerite, and a gangue of biotite and hornblende. The chalcopyrite and chalmersite is an intergrowth of laths of each mineral, with sharp walls which often cut off without narrowing and always end abruptly at the contact with pyrrhotite. The laths vary from ¼ inch in width down to those of microscopic size. This intergrowth is shown in Plate X., *D*. In general, chalmersite, chalcopyrite, and pyrrhotite were formed at about the same time, or very nearly so, while the sphalerite is probably slightly later. The fact that the chalmersite-chalcopyrite intergrowth is cut off sharply at the contact with pyrrhotite suggests that pyrrhotite may be slightly later in some cases.

THE HANOVER (FIERRO) DISTRICT.

Geology.—The Hanover district is situated in Grant County, New Mexico, twelve miles northeast of Silver City, and two miles northwest of Santa Rita. The mines are in the narrow valley of Hanover Creek. The deposits have been described by Graton [9] and by Paige.[10] A mass of quartz-diorite porphyry has intruded Carboniferous rocks, mainly limestone. In general, the sediments dip away from the igneous mass and are much jointed. In the southern part the typical contact rock is largely epidote, garnet, and augite, with quartz, calcite, pyrite, magnetite, and sphalerite. The boundary between the contact rocks and the sediments is usually sharp. The magnetite is said to be near the inner border, the garnet and epidote next, and augite on the outer border. To the north silicification is more pronounced and epi-

[9] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., "The Ore Deposits of New Mexico," U. S. Geol. Survey Prof. Paper 68, p. 313, 1910.

[10] Paige, Sidney, "The Hanover Iron-ore Deposits, New Mexico," U. S. Geol. Survey Bull. 380, pp. 199–214, 1909.

V 18 / 3 A P / M Y 23 UMI

dote-garnet zones more rare. The diorite porphyry has also been somewhat altered.

The ores are arranged around the intrusive along the contact and are, in the main, iron ores, with lesser deposits of copper and zinc. Magnetite, chalcopyrite, pyrrhotite (chalmersite), and sphalerite are the abundant ore minerals. The ores are directly connected with the diorite and, according to Paige, are due to contact metamorphism.

The principal workings are the Republic and Union mines. In places the ore in these mines carries much pyrite and chalcopyrite, and may contain up to 2 per cent. copper.

Mineralography of the Fierro Ores.—The main part of the ore is granular magnetite often rather pure. In some places considerable copper ore is found and the specimens studied indicate that as a rule the copper minerals and magnetite are intimately mixed only along the contact of the two kinds of ore, and that, within the mass, each is relatively free from the other. The ore minerals identified were, in order of abundance, magnetite, chalcopyrite, chalmersite, pyrrhotite, and pyrite. The gangue is quartz and carbonate.

Magnetite is by far the most abundant and is found as granular masses or isolated grains in the sulphides. It appears to have been the first mineral formed with the possible exception of pyrite. Near the contact of magnetite and copper ore, chalcopyrite occupies a matrical position with respect to the magnetite; or isolated magnetite grains occur in the copper minerals. From this relation it is inferred that magnetite was formed early.

Pyrite is not abundant but is always present in the copper ore. It occurs chiefly as isolated rounded grains in chalcopyrite and chalmersite, as if corroded by the later minerals (Plate X., *A*). In places, several remnants of pyrite occur in a single lath of chalmersite, as shown in Fig. 52. Pyrite is also found in a very fine intergrowth with pyrrhotite and sphalerite, rarely with chalmersite and chalcopyrite. The general nature and relations of these areas suggests that the pyrite has been partly replaced by the other minerals. (See Plate X., *B*.) The network of

sphalerite veinlets cutting the intergrowth is especially suggestive of replacement. No definite relation of the pyrite and magnetite was noted except that both are probably earlier than chalcopyrite.

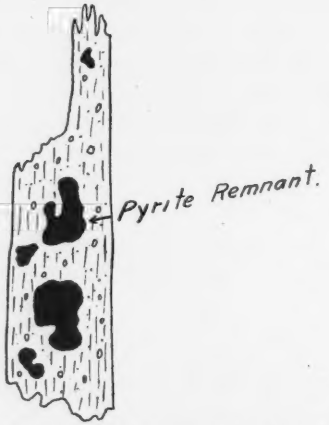


FIG. 52. Sketch showing rounded pyrite grains in a lath of chalmersite. Chalmersite evidently is of later origin and corroded the pyrite. About × 20 natural size.

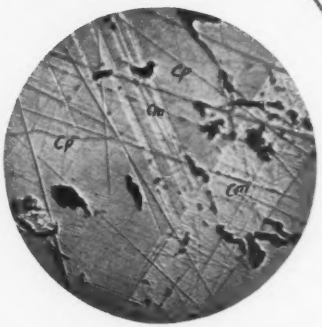
Chalcopyrite is the most abundant copper mineral, and forms considerable masses, but these masses include the other minerals noted.

Chalmersite is found throughout the chalcopyrite in each of the specimens of copper ore from the Republic mine. In the hand specimen it is scarcely to be distinguished from chalcopyrite and pyrrhotite on account of the tarnish. Pyrrhotite tarnishes darker than the other two and thus small veinlets may be traced in the specimens. On a polished surface chalmersite is cream colored to pinkish, compared to chalcopyrite, but cannot be distinguished from pyrrhotite by its color. Examination of polished surfaces shows that chalmersite makes up a considerable portion of the sulphide specimens, and is intimately related to the chalcopyrite. Around the edges of large areas and extend-

A

B

C



D

KANSAS STATE AGRICULTURAL COLLEGE
MAY 14 1923
LIBRARY

A. Corroded remnant of pyrite (*P*) in chalcopyrite (*Cp*) from the Republic Mine, Fierro, New Mexico, Mag. × 75.

B. Pyrrhotite (*Py*) and sphalerite (*S*) replacing pyrite (*P*). Latter partly replaced by fine sphalerite in area marked *P*. Republic Mine, Fierro, New Mexico, Mag. × 130.

C. Intergrowth of chalmersite (*Cm*) and chalcopyrite (*Cp*). Believed to indicate contemporaneous deposition. Republic Mine, Fierro, New Mexico, Mag. × 75.

D. Intergrowth of chalmersite (*Cm*) and chalcopyrite (*Cp*). Compare with (*c*). Parry Sound, Ontario, Mag. × 75.

V
1
8
/
3
A
P
/
M
Y
2
3
UMI

ing throughout the chalcopyrite is an intergrowth of laths of chalmersite; in places both are lath-like. These intergrowths are characterized by straight sharp contacts and intersections with right angles. In places the chalmersite laths cut off abruptly without reference to structures or minerals. A typical example of this intergrowth is shown in Plate X., *C*. This structure is an exact counterpart of the occurrence at Parry Sound, as can be seen by comparing Plate X., *C* and *D*. From the above relations it is inferred that chalmersite is contemporaneous with chalcopyrite.

Pyrrhotite occurs chiefly as veins or stringers cutting chalcopyrite and chalmersite. Some of the veins are as much as ¼ inch wide. It is also abundant in the intergrowths in pyrite described above. Its relation to the other minerals shows that it is somewhat later than chalmersite and chalcopyrite. See Fig. 53.

FIG. 53. Pyrrhotite (Py) veins in an intergrowth of chalcopyrite (Cp) and chalmersite (Cm). The relations show the hypogene origin of the chalmersite and chalcopyrite, since pyrrhotite, a hypogene mineral, is later. Natural size of polished surface.

Sphalerite in part is clearly later than the other minerals, as veinlets and stringers of it cut all of the others. However, it is believed to be only slightly later and possibly in part contemporaneous, since isolated grains are found in chalcopyrite.

There is an absence of minerals and textures which suggest secondary enrichment or supergene action. All of the minerals

noted are believed to be hypogene and formed during the same period of mineralization. The later formation of pyrrhotite shows the primary nature of the minerals. The order of formation is believed to be magnetite and pyrite, followed by chalcopyrite and chalmersite, which are apparently contemporaneous, then pyrrhotite followed by sphalerite.

Chalmersite contains less copper than chalcopyrite and thus its formation is in no sense enrichment. The formation of pyrrhotite later than the chalmersite and chalcopyrite is suggestive, as the iron sulphide in chalmersite has been shown by Palache[11] to be essentially pyrrhotite enriched with Cu_2S to form chalmersite. Apparently iron-rich sulphur-bearing solutions became dominant during deposition with the result that pyrrhotite was formed after the copper minerals. It might be expected that chalmersite would form slightly later than chalcopyrite, thus giving a sequence of minerals of decreasing copper and increasing iron content.

Importance of Chalmersite at Fierro.—The importance of chalmersite from a commercial point of view is chiefly in connection with magnetic ores such as occur at Fierro. Most of the production from the mines of the district is in the form of iron ore. Copper and other sulphides are undesirable. Thus it has been the practice to leave the sulphide ore in place, but it was also desired to utilize this ore for the copper as well as the iron. Magnetic concentration seemed to point the way. It has been previously noted that chalmersite, as well as pyrrhotite, is rather strongly magnetic. Magnetic concentration tests failed to give expected results and the reason for this was unknown until the writer recently discovered the presence of abundant chalmersite.

A partial analysis on a lot of ore which was tested by the Minnesota School of Mines Experiment Station showed Total Fe, 47.27; Mag. Fe, 44.96; Cu, 1.32; SiO_2, 9.01. A magnetic concentration test on the undersize from a 150-mesh screen produced an iron concentrate assaying .51 per cent. Cu, or 40 per cent. of the copper ore in the original ore. The presence of chal-

[11] Palache, C., *op. cit.*, p. 256.

mersite in the ore explains this result. The necessity of some other means of separating the copper, such as flotation, is obvious. It is entirely possible that other cases may be found where this magnetic copper mineral may interfere with magnetic concentration, and in this connection the importance of the study of the polished surfaces of ores for metallurgical purposes is emphasized.

SUMMARY.

1. Chalmersite ($CuFe_2S_3$) is shown to occur at two localities not previously reported: Fierro, New Mexico, and Parry Sound, Ontario.

2. Chalmersite is not a rare mineral but is abundant in at least one locality, Fierro, and probably in Alaska as well. It is believed that a study of polished surfaces will reveal its presence elsewhere.

3. Chalmersite is now known to occur in vein deposits of the deep zone, and in contact-metamorphic deposits. Its occurrence in the latter is reported for the first time.

4. The close association of chalmersite with chalcopyrite and pyrrhotite, both as to place and time of deposition, is indicated by the four occurrences thus far reported.

5. The inability to produce a clean concentrate of copper and iron from the Fierro ore by magnetic separation is shown to be due to the presence in the ore of chalmersite, the magnetic copper-bearing sulphide.

6. A study of the mineral relations of the contact-metamorphic deposits of Fierro shows the order of formation of the minerals to be magnetite and pyrite, chalcopyrite and chalmersite, pyrrhotite, and sphalerite. All are hypogene.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.

KANSAS STATE AGRICULTURAL COLLEGE
MAY 14 1923
LIBRARY

THE SULPHUR MINES OF SICILY.[1]

CORNELIO L. SAGUI.

GENERAL GEOLOGY.

THE Sicilian sulphur deposits are among the most important in the world, and are therefore of interest to geologists who wish to compare the economic geology of Sicily with other mining districts where sulphur deposits occur.

The most striking characteristic of these sulphur deposits is their great extent. They occur in a broad and long zone which cuts the entire island in a general diagonal direction, following roughly an east-west line from Ætna to the small island Pantelleria. This line is well defined by a Pliocene uplift, principally of sandstone, which forms the central orographic system of Sicily. At its base is a Miocene shale, with an average thickness of 800 to 1,000 feet. The sulphur mines in this uplift have been worked from the earliest times, but industrial mining is a comparatively recent development, beginning with the past century.

The succession of sedimentary rocks cannot be well defined, but as a general rule there is at the footwall of any sulphur deposit a bed of tripolite of thickness ranging from a few feet to several yards. At the Passarello mines, for example, the tripolite reaches a maximum thickness of 135 feet. Among the fossils commonly found in this rock are *Lebias Crossicaudus* and *Leuciscus Coningensis.*

The following is an analysis of the average tripolite of Passarello:

	Per Cent.
Silica	0.669
Al_2O_3	0.042
$CaCO_3 + MgCO_3$	0.118
Organic substance	0.172

Frequently there occurs immediately above the tripolite a characteristic siliceous limestone, from a few inches to a few feet

[1] Rewritten by Editor.

thick, which is as a rule the rock in contact with the bituminous shale next to which the sulphur is found. The thickness of this layer of limestone seldom exceeds four feet.

SULPHUR DEPOSITS.

Scattered along the uplift described above are found a large number of sulphur deposits of varying extent, but the typical formations are those around the famous mines of Testasecca and Solfara Grande. At these mines work is still progressing, though slowly, because the deeper levels contain lower grade material and mechanical appliances are still primitive. Careful observations have been made at these deposits which may add to the general knowledge of this phase of economic geology. Among the more important observations are the following:

1. At the Racalmuto mines fossil fish are found similar to those found in the tripolite formation, imbedded in a sulphur deposit of poor quality with a gangue of shale and clay.

2. This never occurs where limestone is the principal gangue of the sulphur ores.

3. Where the strata are more disturbed, the sulphur deposits seem richer.

4. The sulphur deposit is generally covered by a layer of gypsum, but frequently between the sulphur and gypsum a thin layer of shale is found, mixed with a peculiar sand of marcasite and boulders of sandstone.

5. As a rule, gypsum following the main sulphur formation is crystalline and formed by a uniform and compact mass of minor elements.

6. Sometimes above the gypsum a layer of clay is found in which lenses of sulphur ore are disseminated. This secondary formation is followed by another variety of gypsum called Upper Gypsum, more coarsely crystallized than the gypsum considered under No. 5. Many fossils of *Lebias Crossicaudus* were found in this Upper Gypsum at the Racalmuto mines, and at Grastupa the following fossils have been found: *Robulina Antiqua, Nummulina Irregularis,* and *Nodosaria Raphanistrum.* The cap of

the entire formation seems to be a rock called Trubo (shaly limestone) which belongs to the Middle Tertiary and generally overlays the Upper Gypsum. The fossils occurring most frequently in this shally limestone are: *Globigerina Bulloides, Globigerina Regularis, Orbulina Universa D'Orbigny.*

ORIGIN OF THE SULPHUR DEPOSITS.

Motura's explanation of the origin of the sulphur ores is the most convincing, and his hypothesis still has a large following among our scientists, although many others have been proposed. His work is based on the following equations:

$$CaS + H_2O + CO_2 = H_2S + CaCO_3,$$
$$H_2S + O = H_2O + S.$$

These equations give a simple explanation of the origin of sulphur deposits, but unfortunately a study of the deposits shows that the conditions under which such chemical reactions might have occurred are not so simply found.

Hoffmann, Bischoff, and Poillette supposed that sulphur deposits originated by the emanation and decomposition of H_2S through fissures and holes of preëxisting rocks. It is very probable that sulphur and gypsum were generated by H_2S, but in my opinion this gas was in solution in underground waters. Many observations carefully made at different places seem to prove that the H_2S in the Miocene horizon was of magmatic origin.

It was also supposed that the sulphur might have originated from the reduction of gypsum by the hydrocarbons of the tripolite, but such a reduction seems impossible, at least as a general rule, for the proportion of sulphur to the H_2S is not sufficient to develop in the above reaction. It also seems illogical to admit, as many geologists do, that gypsum is a product of sea-water deposition; the gypsum is frequently interbedded with clay, limestone, and sulphur, which would have to be explained by an intermittent deposition of $CaSO_4$, varying greatly from place to place, which is contrary to the simple laws of nature.

This conclusion does not exclude the possibility of marine

origin for some of the gypsum, but it is certainly the smallest part and practically without importance for the main sulphur formation. In any theory up to the present time, however, proposed in explanation of the Sicilian sulphur ore deposits, no consideration has been given to the modern ideas, which attribute enormous importance to the work of underground water in any ore deposit, especially in connection with magmatic intrusion in a sedimentary horizon.

My purpose is to consider the origin of the sulphur ores in the light of these modern views. One striking feature to be pointed out is the presence of basalt rocks along the southeastern boundary of the sulphur region, and of other eruptive rocks, not yet studied, near Racalmuto, the center of the sulphur-bearing measures. Very probably, in my opinion, such a magmatic flow carried with it a large quantity of H_2S, which was dissolved in the underground water and poured out by the numerous springs of that period. It was thus mingled with the water of streams, rivers, ponds, and lakes, aiding and modifying geologic processes by its deposition and chemical work.

One of the best examples of sulphur formation I have studied is at the Passarello mines near Licata, in the southwestern part of the Sicilian formation. Fig. 54 is a cross section of one of

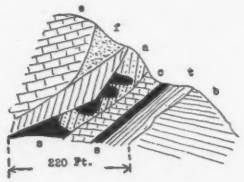


FIG. 54. Sketch of vertical section at Pero. *a*, gypsum; *b*, clay; *c*, limestone; *f*, shale; *s*, sulphur; *t*, tripolite.

the more disturbed zones of this mine. It appears that three different phases of deposition have taken place. Part *c-t-b* seems to be the regular and steady work of deposition on the bottom of a lagoon during a long period of tranquillity; the second part,

a-f-e, shows how the soil was subjected to frequent movements which changed abruptly the natural deposition of the sediments, causing a marked difference in the thickness of the strata within a very small area. Stratum *a* is an irregular one and is formed principally by gypsum and sulphur. The sulphur, as we have noted, was derived from the following reaction:

$$H_2S + O > H_2S + S,$$

and the gypsum is a transformation of sulphur and underground water through secondary processes. It has probably undergone the following chemical change:

$$CaCO_3 + H_2O + S = CaSO_4 + CH_2.$$

We do not actually know the transitional reaction which may have occurred to reach this synthetic one, but it is a fact that transformation does take place in this way. As evidence, I have investigated a large number of deposits where the above chemical changes are still going on, and the gradual change of sulphur and gypsum can be readily seen. Characteristic parts in many deposits show a complete series of transformations, giving substantial proof to the theory.

It is also important to observe how the zones richest in sulphur were formed through secondary processes by underground water. The sulphur of the upper part of the strata was partially, sometimes totally, leached down. For this reason, barren limestone is found carrying sulphur. A fine example of this was observed at the Testasecca mines, where, in the central part of the formation, the strata are barren for a distance of about 300 feet. The barren limestone is cavernous on account of the leached-out sulphur, but it still has the same character as the mineralized limestone.

Along the outcrop of the lodes the sulphur has undergone a double transformation caused by leaching due to water and the work of atmospheric agents. The product of such a double trans- gypsum in part not yet crystallized, and also retaining the primi- formation is called Briscale, which is generally limestone with

tive structure of the vanished metalloid. We have many instances where the sulphur is replaced by gypsum along the same lode for some distance; where the transformation of sulphur into gypsum is evident. One striking example of this occurs at the Solfara Grande, one of the largest mines in Sicily.

At the Passarello mines (Figs. 55 and 56) I had the opportunity

FIG. 55. Plan of Passarello sulphur mines.

to make a detailed study of the formation of sulphur. Here, there is a long outcrop of limestone, forming a double-S-shaped range of barren hills and domes, gently sloping and frequently broken

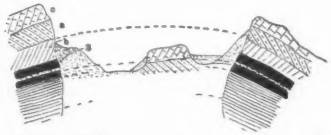


FIG. 56. Section *A–B* of Fig. 1. *a*, gypsum; *b*, clay; *c*, limestone; *s*, sulphur.

into picturesque ravines. Two main valleys, trending approximately north and south, drain the scanty water of the brief rainfall period of Sicily into the Salso river—so called from the quantity of NaCl it carries in solution, dissolved by the water in passing through the saline clays of the Miocene. The southeastern valley is the larger, formed by two parts of the same series of strata. In the central part of this formation only a few cores of limestone remain; the greater part of the strata up-

lifted during Miocene time has been almost entirely eroded, not more than six miles distant from the Passarello mines.

The thick series of alternate layers of limestone and tripolite (Fig. 57) indicates favorable conditions during the long period

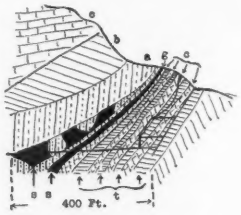


FIG. 57. Sketch of vertical section at Cerasela. *a*, gypsum; *b*, clay; *c*, limestone; *s*, sulphur; *t*, tripolite.

of deposition for the development of diatoms; but when the water began to carry H_2S in solution, the favorable conditions ceased, and the last bed of limestone, lying immediately above the last layer of tripolite, is followed by a deposit of sulphur. That such deposits were secondary is readily proved by observation. The layers at the footwall of the sulphur deposit are permeable, and the fissures and druses of the footwall are filled with sulphur coming from the upper strata. The sulphur was leached down during a long period of transformation, solution, and deposition.

The origin is not always epigenetic; sometimes syngenetic formations occur, in which case the sulphur is concealed by a mantle of clay. The finest example of this is found at the Lucia mines, Favara. The change of sulphur into gypsum within the deposits is due to the slow work of underground waters. Substantial evidence for such a transformation is found in the fact that many sulphur crystals have changed into gypsum. As further proof, the structure of the gypsum is more compact, owing to the pressure developed by the increase in its volume. Many experiments have proved that gypsum thus formed by transformation underground has a higher specific gravity than gypsum which has

crystallized freely in the water of a lagoon, with an abundance of atmospheric oxygen.

The atomic weights show clearly the effect of the transformation:

$$\left.\begin{matrix} CaSO_4 = Ca + S + O_4 \\ 29 + 20 + 50 \end{matrix}\right\} = 100,$$

$$\left.\begin{matrix} CaCO_3 + S = Ca + S + CO_3 \\ 20 + 46 + 31.20 \end{matrix}\right\} = 100,$$

$$\begin{matrix} Ca \\ 66.7 - 20 = 46.7, \end{matrix} \qquad \begin{matrix} O_4 - CO_3 \\ 117.3 - 31.2 = 86.1, \end{matrix}$$

$$46.7 + 86.1 = 132.80,$$

$$132.80 + 46 = 178.8.$$

46 per cent. is the average percentage of sulphur in the ore. The resulting figures give to the weight of the whole a considerable increase; consequently the volume also will change by a ratio easily found by comparing the specific gravities of $CaSO_4$, $CaCO_3$, and S. No water of hydration is considered here. We can now imagine the enormous pressure exerted on the bounding rocks of the strata, and also on the gypsum so formed. A close study of the structure of the gypsum reveals the effect of the intense stress of this enormous pressure. Important mechanical changes are also caused by these chemical changes, sometimes modifying the topographic outline of a considerable area of surface.

The transformation above noted is clearly shown in the Aliastro section (Fig. 58) where the phenomenon was thoroughly studied. The limestone of the bed *S* was probably carried to the bed *s*,

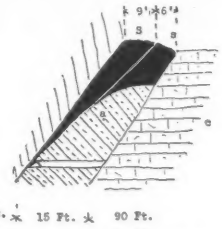


FIG. 58. Sketch of vertical section at Agliastro. *s*, sulphur; *S*, sulphur; *a*, gypsum; *c*, limestone.

where the chemical change of sulphur into gypsum took place. At the same time part of the sulphur was leached down by the same solution and carried elsewhere to form secondary deposits. The sketch shows the division between the strata *S* and *s*, formed by a seam of permeable material, where the effect of the pressure is everywhere visible.

The occurrence of celestite (S_2SO_4) in the sulphur deposits is worth noting. It is found as stocks from a few inches to many feet thick. At the Passarello mines, the sulphur beds carry celestite next to the footwall rocks, but the quantity is small and the beds are not workable. The origin of this secondary material is probably the same as that of the sulphur. Evidence of this is found at the Tivoli sulphur springs near Rome, where the waters carry in solution with H_2S a certain quantity of $SrSO_4$.

Another characteristic sulphur ore is found at the Passarello mines, called Soriata on account of its stratified structure. It was studied by the writer with especial care, as Motura and other geologists found in it the strongest argument for the sedimentary origin of the sulphur deposits. A close investigation shows that the structure is a simple phenomenon of re-crystallization. In fact, the supposed layers are not on the same plane as the limestone and sandstone strata. No other facts, moreover, were found to give weight to the supposition that the formation was due to sedimentation. It appears clearly that the limestone forms a sort of network, in which the underground waters carrying H_2S have slowly built up the sulphur deposits.

CONCLUSIONS.

What I have here sketched briefly has been studied through a long period of mining operations and has convinced me that the sulphur had a secondary origin, occurring at the time of the basaltic eruption, which carried with it a large quantity of H_2S. Further evidence for my conviction is found in the fact that the sulphur deposits are not regularly distributed, but diminish

in richness from a central zone outwards, proving that the more important deposition took place near the H_2S springs.

H_2S dissolved in water seems to have been the principal factor in the origin of the gypsum as well as the sulphur deposits. A simple explanation for the formation of large quantities of gypsum would be the meeting of two springs in a lagoon or pond, one carrying $CaCO_3$ and the other H_2S.

The marine origin of gypsum is not so easily explained; it seems strange to think of an ocean which deposited through many centuries only $CaSO_4 \cdot 2H_2O$, although gypsum separates when sodium chloride, for example, is held in solution.

We may therefore understand more readily the conditions under which anhydrite, not gypsum, was first formed; anhydrite was changed into gypsum only in a secondary transformation. In every place where the gypsum formations were studied, it was always difficult to accord the observations with the theory of marine origin; it was necessary to imagine some peculiar and constant conditions contrary to the normal work of nature. Limestone frequently occurs in the Sicilian mines completely intermingled with gypsum, suggesting that the deposition of $CaCO_3$ has gone on simultaneously with that of H_2S, but without the same intensity.

It would be interesting to apply the above criteria to some other country.

FABRIANO,
ITALY.

EDITORIAL

FIELD VERSUS LABORATORY EVIDENCE IN THE IDENTIFICATION OF METAMORPHIC ROCKS.

After examining the field conditions and relations of metamorphic rocks, we hopefully carry home specimens for microscopic and chemical examination. When laboratory methods fail to solve the problem of origin, we return to the field for more evidence. Alternation of these methods of study in time may bring a definite conclusion—both are necessary—but when the evidence is reviewed, it has been my experience that the field and structural evidence is usually more decisive than that found in the laboratory. It would be interesting to know to what extent this experience accords with that of other investigators. There are some at least who seem to reverse the emphasis, even to the extent of reaching definite conclusions from petrographic study without seeing the field conditions.

Rarely does the deformation of rocks go so far as to destroy beyond the possibility of reconstruction, the main outlines of formations, their thickness, continuity, field relations, or even some of their textures. A formation may be thickened or thinned by folding and flowage, and it may be much fractured and faulted, but it is usually possible to get some idea of its original morphology. Even deformation as extreme as rock flowage, producing schists, does not always destroy evidences of original structures, like bedding, or ellipsoids, or amygdules. Likewise, contact metamorphism seldom fully destroys either the major outlines or the principal structures for all parts of a formation. The general manner of weathering, the behavior under fracture or flow, the color, the texture, the breaking or sound under the hammer, in short, the "habit" of large masses of rock as seen in the field may collectively give a clue to origin,

even though no single criterion is decisive. Perhaps the most important advantage of field over laboratory observations is that they are not limited to specific samples, but cover the complete range of variations. Gradations may be traced from obscure to identifiable forms, and thereby the changes peculiar to the given rocks and environment may be empirically recognized.

Laboratory study of the mineralogical and chemical composition and texture, of course, is a valuable aid in the identification of origin. Sometimes this is decisive, even when the field evidence is doubtful. Seldom, however, is it sufficiently conclusive to over-ride field evidence. Metamorphic changes are often so extensive and varied that the new characteristics are unsafe guides to the old ones unless we know the local habit from field observations. The distinctive characters of sedimentary and igneous rocks become obscured and hopelessly mixed. There is, moreover, a distinct tendency for metamorphism to produce common types, characteristic of the given environment, from rocks of widely different type and origin. A chlorite schist, for instance, may result from dynamic metamorphism of a basalt or a shale. A hornblende schist may result from the contact metamorphism of the same rocks. A mica schist may be formed from a quartzite, a shale, or a granite. The chemical composition of the schist may reflect more the composition of its platy or columnar constituents like chlorite, mica or hornblende, which are characteristically formed under the schist-making conditions, than it does that of the original rock.

In a short editorial there is little space for illustration, but we may refer incidentally to the question of the origin of the iron ores and associated gray gneisses of the Adirondacks. They extend in sheets over considerable territory, and are associated in more or less definite sequence with certain undoubted sedimentaries. They are folded and faulted together. They contrast in their structural regularity with the shear planes in the gabbros and eruptives, which are not constant either in direction or continuity. They are regarded by some geologists as sedimentary and by others as igneous. The two points of view

are respectively summarized by Nason[1] and Miller[2] in recent numbers of this Journal. All of the geologists who have studied this region have considered both field and laboratory evidence, but it is clear that the advocates of sedimentary origin on the whole stress the structural and field evidence, while the advocates of igneous origin lay relatively more stress on the petrographic evidence. So far as I have seen the evidence, in the principal producing district about Mineville, the structural features seem to me to favor the hypothesis of sedimentary origin and to outweigh the metamorphic evidence. In this view I am doubtless influenced by experience in other fields in which structural features have afforded the more decisive criteria.

C. K. LEITH.

[1] Nason, Frank L., "The Sedimentary Phases of the Adirondack Magnetic Iron Ores," ECON. GEOL., vol. 17, 1922, pp. 633–654.

[2] Miller, William J., Nason on "The Sedimentary Phases of the Adirondack Magnetic Iron Ores," ECON. GEOL., vol. 17, 1922, pp. 709–713.

DISCUSSION AND INFORMAL COMMUNICATIONS

SEDIMENTARY PHASES OF ADIRONDACK MAGNETITES.

Sir: F. L. Nason's paper on the Adirondack magnetites (ECON. GEOL., vol. XVII., December, 1922) gives an insight into some of the complexities which the student of Adirondack geology encounters. It consistently follows certain evidences in support of one theory of the origin of the ores and plainly shows, what I am thoroughly convinced of, that the matter has not yet reached the stage of finality. Detailed investigation of a particular district, following out the structures and physical conformation of the deposits as developed by underground exploration or drilling, supplies valuable information, but in the tangle of igneous and sedimentary formations, affected by injection, assimilation and metamorphism, recourse must also be had to the methods and tests of the laboratory, more particularly of petrography. There is hardly space in the limits alloted to discussion to do full justice to the many questions raised in the contribution. I should like, however, to bring under review a few points that seem to call for special notice.

The first of these concerns the use of ilmenite as a reliable criterion to distinguish between the ores of igneous—anorthosite, gabbro and syenite—rocks and those of the Grenville and of the gray gneisses which Nason implicitly regards as sedimentary or Grenville. In passing, it may be noticed that gray is perhaps a distinctive enough word for the country rock at Mineville and Hammondville, but is hardly applicable to other large districts. But the point in mind is that ilmenite has a subordinate place as an ore even in the basic igneous rocks, and if there are any pure ilmenite deposits in the Adirondacks they have not been brought

to general notice. The so-called ilmenite ores are mixtures (intergrowths) of that mineral with magnetite. In the best known examples of such ores the ilmenite never reaches as much as one half of the percentage of magnetite. Analyses of the Lake Sanford deposits show from 20 per cent. TiO_2 maximum to around 6 or 8 per cent. minimum as compared with 52.7 per cent. demanded for pure ilmenite. The magmas contained insufficient titanium, apparently, to combine with all of the iron and form ilmenite alone or even a predominant fraction of ilmenite. It is this feature which holds encouragement for the practical utilization of these ores in iron manufacture.

On the other hand I am not sure, correctly speaking, that titanium-free ores occur anywhere in the Adirondacks. If I am mistaken as to this matter, I shall be glad to be corrected. At any rate the expression titanium-free should be applied in the broader sense of an appreciable quantity. Even so, there is some ground for the particularist, whose viewpoint is hardly my own, to raise an objection to such a generalization. For example, there is as much as 4 per cent. TiO_2 in the magnetites of the Clinton county districts, nearly all of which occur in a reddish rock of granitic composition that extends for some 60 or 70 miles along the northern Adirondack border in almost unbroken continuity. This reddish rock holds the Lyon Mountain ore bodies and those of Palmer Hill, Arnold Hill and many other localities. In the Lyon Mountain concentrates, according to analyses supplied by Mr. James Brakes, mine chemist, there is 0.4–0.5 per cent. TiO_2 The Benson Mines mill product carries about 1 per cent. TiO_2 as shown by analysis.

A rather remarkable example of the occurrence of ilmenite in a deposit not associated, directly at least, with gabbro, anorthosite, or syenite, is to be seen at the Port Leyden mine, on the west side of the Adirondacks. The wall rock is a microcline-quartz-biotite mixture, a slightly foliated granite, to all appearances. An analysis of the ore contained in an early report showed 9.31 per cent. TiO_2, which was surprising enough to invite further investigation. Samples were taken from the mine and

were analyzed by Prof. E. W. Morley who reported 9.90 per cent. TiO_2, with 50.79 per cent. Fe, which places the ore in the class of the basic igneous deposits, so far as titanium is concerned.

There would seem to be no absolute principle governing the distribution of ilmenite along the lines of rock classification. Its habits, however, are generally pyrogenic in the sense that it favors the plutonic rocks. In the Adirondacks it seems to be a general rule, although not without exceptions as noted, that the basic or quartz-free rocks carry titanium combined with iron, whereas the syenites with low free quartz, and granites with their high quartz have the titanium combined in the form of titanite. The last mineral is a very common ingredient, although a minor one, of the low-titanium ore-bearing formations, which in places are distinctly colored by the mineral. Lyon Mountain is a case in point.

At any rate the typical green syenite has magnetite as a common mineral. The quarries about Ausable Forks, which produce an attractive dark-green monumental stone from the syenite that is exposed there in very massive ledges of uniformly textured and heavily jointed material, supply a good illustration of the character of the magma when unmixed with other rocks—a rather rare condition for both syenite and granite in this area. The northern edge of the syenite lies close to Palmer Hill in contact with the reddish ore-bearing formation. Both rocks carry fluorite as a regular constituent and, except for the differences in quartz content, are similar mineralogically. Both are likewise surcharged with magnetite, which in the syenite averages 5–10 per cent., as indicated by crushing samples and weighing the iron mineral recovered by a small hand magnet. The Salisbury mine of the southern Adirondacks lies within gneissic syenite; the ore, so far as analysis would indicate, is not appreciably titaniferous.

It is fairly established in the opinion of geologists that the ores in anorthosite and gabbro are local segregations of iron oxide contained in the magmas. It seemed pertinent, therefore, to obtain an estimate of the iron carried by those rocks for comparison with the percentages in the syenite-granite group. From the various State and Federal Survey reports that are at hand I have

obtained 30 analyses altogether of representative Adirondack rocks, or regarded as such by those who described them, but it is likely they do not include the full list of such analyses available from trustworthy sources. They are taken as they are available. Six analyses of anorthosite were found and they averaged 3.71 per cent. iron oxides; eight gabbros averaged 10.66 per cent. oxides; sixteen syenites and related granites averaged 6.59 per cent. iron oxides. Roughly, the proportions of iron oxides are thus 1 : 3 : 2 for the three rock classes. All of the syenite-granite examples analyzed came from localities outside of the iron districts and would appear to indicate about the normal percentages for those magmas. If segregation of iron has not taken place locally in them it is hardly owing to deficiency of iron. The fact that such a process is not so readily conceded in the one case as the other is accounted for, I believe, by the greater mobility of the more acid materials. In other words, the differentiated products have not always, or perhaps commonly, remained in place, but have partaken of the migrant habit of the hosts which essentially were solutions or mineral juices rather than products of dry fusion or slags.

Given a tenuous condition through the presence of mineralizing agencies and pressure on the magma there seems no difficulty in explaining the elongated lenticular bodies that characterize the occurrences in some of the mining districts, nor the feature of parallelism between the major axes of the bodies and the more or less distinct foliation of the wall rocks. Much of this apparent foliation is really original pressure effects or magmatic flowage in conformity with the cooling surfaces and not a secondary gneissic structure. In the case of sills that have penetrated along the bedding of Grenville schists, there results a conformable arrangement between the foliation of the granite or syenite and the schistosity or bedding of the sediments, which have had a directive influence upon the course of the magma. In other words the latter has molded itself to the former.

It is possible, I believe, to insist too strongly upon the continuity of the low-titanium ores and their regularity in the plane of their

maximum development. Single deposits do reach a mile or so in length on the surface and correspondingly extended depths, but when it comes to a matter of several miles the ores are distributed among a number of bodies that occupy altogether a fairly wide zone with barren intervals between the successive deposits. The individual bodies may exhibit almost every variation of shape, from tabular masses to short lenses, pods, and horns enclosing horses of the country rock, and range down to mere wisps of disseminated magnetite in the wall rock. These zones are elongated in a northeast-southwest direction, but so are the granites and gneisses, an inheritance perhaps of an early defined line of weakness marked out in the old Grenville. The anorthosite alone of the intrusives seems to have been capable of forcing its own path upward, to have shouldered off the sediments rather than mingle with them. There is a noticeable rarity of anorthosite dikes or other off-shoots of the great massive that occupies the central Adirondacks. None the less, the main ore bodies occupy a rather limited area or zone with a major axis about parallel with the general structural trend.

In the last analysis the crux of the whole matter as to the derivation of the magnetites lies in the classification of the wall rocks. One may draw the line between typical Grenville and typical syenite, or granite, fairly easily. There is a goodly residuum of materials, however, that are not typically the one or the other, but if anything a blending of igneous magma and sediments due to the partial or complete assimilation of the latter in invading rock. In that sense, perhaps, there is no sharp division between such ore bodies as those for example of Lyon Mountain and Palmer Hill, which I take to represent the igneous type and those in more or less close association with Grenville schists, gneisses or limestone, such as the deposits at Benson Mines, Jayville, and Clifton. In the latter the Grenville is quite highly modified by granite injection, and it may be an open question whether the iron is the contribution of the one or the other. At any rate the influence of the Grenville environment is apparent in the pyritic, garnetiferous, hornblendic character of the ores.

It is noteworthy that the main Grenville areas, least broken and injected, carry no ore bodies of any account. I refer to the areas in southern and western St. Lawrence county in which the sedimentary succession is best developed and has the least admixture of other rocks.

ALBANY, N. Y.

D. H. NEWLAND.

PRE-GLACIAL OXIDATION IN NORTHERN ONTARIO.

Dear Sir: In a letter published in the number of ECONOMIC GEOLOGY for July–August, 1920, pp. 453–454, I drew attention to the existence in Northern Ontario of pre-glacial oxidation and decomposition of the rocks, and gave instances of such decomposition from the Porcupine District and from the Matachewan District fifty miles to the southeast of it. Other instances might have been cited, such as a residual deposit near Sturgeon lake which was worked for a short time as a placer mine, and the glaciated surface of gossan near the Creighton mine, but the two instances mentioned in my former letter seemed quite sufficient to exemplify my point.

However, in the number of your journal for December, 1921, pp. 558–561, Mr. A. R. Whitman challenges the correctness of my observations and statements, and then disregarding them entirely says that "residual soil of pre-glacial age is thus far unreported from the surface overridden by the Pleistocene glaciers of Ontario."

In ECONOMIC GEOLOGY for June–July, 1922, Dr. A. P. Coleman, late professor of geology in the University of Toronto, and one of the ablest students of glacial geology, gives a number of instances of the occurrence of residual soil of pre-glacial age in different parts of the Province of Ontario, extending from Michipicoten, north of Lake Superior, southward to Toronto and Niagara.

But perhaps the most interesting record of the occurrence of pre-glacial exidation in northern Ontario was given by Dr. J.

Mackintosh Bell in a paper which he read before the Institution of Mining and Metallurgy of London, on the 16th of February last, and which was published in the *Bulletins* of the Institution for February and March, 1922, describing a silver vein in the Keeley Mine in the South Lorrain District, 20 miles southeast of Cobalt, in northern Ontario. This vein, and others in the immediate vicinity, are in pre-Cambrian greenstone and diabase, and consist for the most part of calcite, smaltite and native silver. The vein itself and the adjoining country rock is shown to have been oxidized and decomposed to a depth of 420 feet at least, which was the greatest depth then reached in mining, and that this oxidation was undoubtedly pre-glacial in age.

In these conclusions Dr. Bell is confirmed by Mr. C. W. Knight,[1] Assistant Provincial Geologist of the Province of Ontario.

In view of the above records of facts, it will be necessary for those dealing in any way with ore bodies in northern Ontario to realize that the glaciers which covered the country during the Glacial period did not carry away all the soft, oxidized, or residual material, and that such material may still be found in many places under a covering of boulder clay.

CONFEDERATION LIFE CHAMBERS,
TORONTO, ONT., CANADA.

J. B. TYRRELL.

1 *Engineering and Mining Journal*, May 6, 1922, pp. 761–768.

REVIEWS

The Mineralogy of Pennsylvania. By SAMUEL G. GORDON. The Academy of Natural Sciences of Philadelphia, 1922. 255 pages. $2.75.

This pamphlet includes a brief but informing history of the development of mineralogy in Pennsylvania, an elaborate arrangement of minerals according to origin, and an up-to-date summary of the main geologic features of the State. Then follows a list, covering more than a hundred pages, of all the mineral species thus far recognized to occur in the State, arranged according to Dana, with brief summaries of their properties, with practically every published illustration reproduced, and with every analysis on record faithfully copied. About 300 minerals, including many rare and unusual ones, are represented; no doubt it will be a surprise to many to be reminded that the mineral celestite was first discovered in Pennsylvania, and that scheelite, monazite, uraninite, and other rare metal minerals occur there in more than one locality.

The mineral localities yielding the species listed are then tabulated by counties and townships, all definitely known ones being exactly located on U. S. Geological Survey topographic maps by a coördinate method. Lists of the minerals found at each, with references to the place of publication of the report, are given in full, so that it is an easy matter to ascertain what is to be looked for at any given place. An unusually complete bibliography of articles on the minerals of the State, and an index of species, with a few localities, completes the work. In accuracy and completeness it would be difficult to improve upon this compilation, and it represents a mine of information to any one seeking information on the minerals of Pennsylvania.

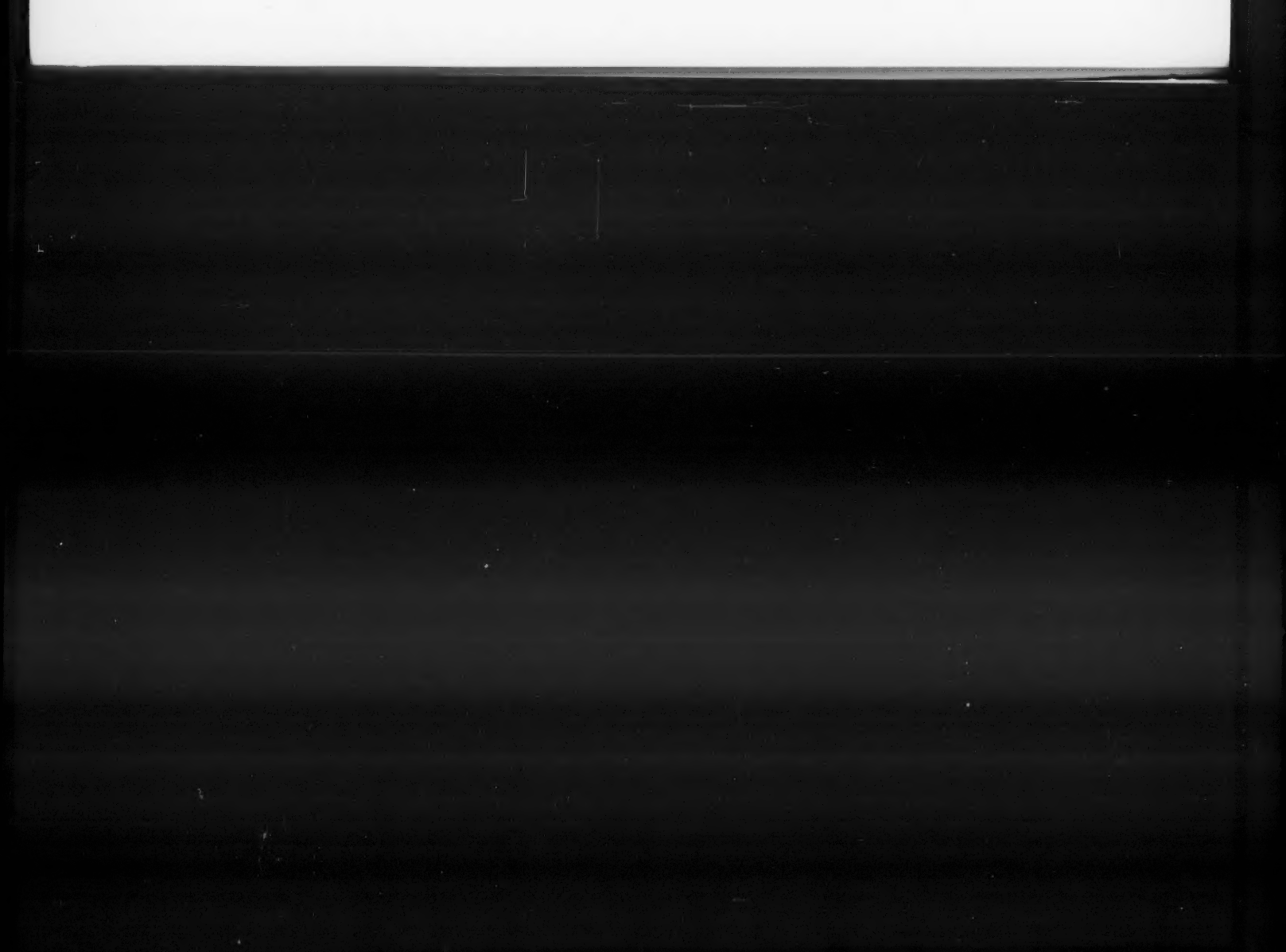
EDGAR T. WHERRY.

WASHINGTON, D. C.

The Graphites and Coals of the Turukhansk Region. By S. V. OBRUCHEV. Mining Journal, 1922, No. 3–5 and 6–9, pp. 132–142, 274–294. Moscow.

The Norilsk Coal-Bearing Region. By N. N. URVANTSEV. Bulletin of the Siberian Section of the Russian Geological Committee, vol. II., No. 1. Tomsk, 1921. (Both in Russian.)

Up to the years 1910–1912 the data concerning the geology of the vast country of Siberia were extremely meager, and the opinions commonly



held regarding the immense mineral resources of the country were not based on facts. Systematic explorations of Siberia were begun in 1912; and the further these exporations are carried out, the more data we are gathering in support of the belief in great mineral resources.

In the report on the coal resources of Russia compiled for the XII. International Geological Congress held in Toronto, Canada, in 1913, the Russian Geological Committee could not estimate the resources of the Kuznetsk basin at more than 12.5 billion tons, though believing that the actual resources of the basin were much greater. The explorations made in 1913–1915 clearly established the truth of this belief, and have led to the conclusion that the resources of the Kuznetsk basin can be estimated at 250 billion tons at least—20 times greater than the previous estimate.

Now some new successful explorations of the Siberian coal areas may be recorded, important not only for our conception of the coal resources of Asia, but also for the understanding of the geological history of the continent.

Numerous outcrops of coal beds in the system of the tributaries to the right of the Yenisei River have been known for a long time, and the report of the Russian Geological Committee recorded the location of a great number of coal deposits in this region. In addition to these, a new coal basin has been described by Mr. S. V. Obruchev, one of the geologists of the Russian Geological Committee.

In 1918 Mr. Obruchev published a paper, "The Tungusk Coal Basin,"[1] in which he summarized the data on the region lying between the Lena and Yenisei Rivers, and concluded that a large coal basin exists in this region. During the following three years several explorations in various parts of the region were made, and supplementary data were collected which enabled Mr. Obruchev to describe the region in more detail, particularly the western part, in an article entitled "Graphites and Coals of the Turukhansk Region." The following are some of the most interesting extracts from these articles.

The Tungusk coal basin occupies a vast area of about 900,000 square kilometers. Its boundaries may be roughly outlined as follows: southward the basin extends to the junction of the Ilim River with the Angara River; eastward it reaches the middle part of the Vilui River; in the north it includes the Norilsk Mountains, the lower part of the Khatange River, and probably a considerable part of the Taimyr Peninsula; the western boundary of the basin follows the Yenisei River, crossing it between the Lower Tunguska and Stony Tunguska Rivers and extending almost to the Tas River.

[1] "Rudnyi Vestnik," vol. II., No. 1–4.

The deposits forming the basin may be divided into two series. The older one consists of gray and green sandstones and shales, with stringers of coal-slates and beds of coal. It forms the western part of the basin, overlying a Silurian formation folded conformably to it, and is intersected by numerous faults, and intrusions and dikes of trap. The central part of the basin, as well as its southern and probably eastern borders, are formed by an earlier series, which consists of sandstones and clays. Though lying almost horizontally, it is also intersected by numerous faults and intrusions and dikes of trap.

The character of the coal in each series is essentially different. The coals found in the earlier series have undergone but slight metamorphism, and in some cases show a transition to lignites. They form lenses hardly more than ten kilometers across. The coals interbedded with the older series are much more constant in quality and thickness along the strike. They are strongly metamorphosed, having been involved in the folding, and also at many places have undergone metamorphism by trap intrusions and have been changed into graphite.

The age of the Tungusk deposits, according to examination of the fossil plants (*Nœggerathiopsis æqualis* Goeppert, *Phyllotheca deliquescens* Goeppert) collected from various parts of the basin, is determined by M. D. Zalesskii as Permian or Upper Carboniferous. Some brachiopoda and Lamellibranchiata found in the Fatianikha River and in the Norilsk Mountains prove that at the time the older series was laid down the basin was covered by the sea. The early history of the central part of the Tungusk region still remains unknown, but one may presume that at the time of the deposition of the younger series the basin was occupied by the littoral part of the sea and its lagoons, and to some extent by fresh water basins.

Approximately 30 per cent. of the total volume of the Tungusk series consists of trap intrusions, flows, and dikes; the remainder consists of the series without other interruptions. In the western part of the basin there is an interrupted belt of coal-seams extending about 465 miles without any change in the character of the coals. For this reason, as well as for the fact that the mode of geological occurrence of the coal-beds is practically the same throughout the entire area, the author believes that the Tungusk region may be considered as one continuous coal basin. He states, however, that its vast area, though much larger than any other known coal-basin, gives no foundation for judging of its real economic importance. The data at the present time are not complete enough to estimate the resources or to show its relation to the economic welfare of the country. Of the great number of coal deposits known to exist within the area of the region, information can be given of only a few.

In the northwestern part of the Tungusk basin is situated the so-called Norilsk coal-bearing region, explored in 1919–1920 and reported upon in 1921, by N. N. Urvantsev.

The region is located between the parallel 69° and 69° 40′, and between the meridians 57° and 58° 40′ east of Pulkovo. Its total area is about 2,150 square miles. The coal deposits are found 50 miles east of the village of Dudinka on the Yenisei River, and 66 miles southeast of a port at the mouth of the river, the construction of which was begun in 1917.

The region is formed principally by coal-bearing strata, the lower part consisting of marls, and the upper part of sandstones and clay slates. The fossil plants found in this region (*Cordaites acqualis* Goeppert sp., and *Phyllotheca* cf., *deliquescens* Goeppert sp.) indicate lower Permian age. The strata lie almost horizontally, partially covered with trap-flows and crossed by dikes and laccoliths.

The sedimentary rocks near the igneous rocks show an intense metamorphism. As a result of this metamorphism the content of volatile matter in the coal decreases, so that the coal which in its unaltered state belongs to the fourth class of Grüner's classification (percentage of volatile matter ranging from 19.5 per cent. to 25 per cent.) passes into hard coal and anthracite at a distance of 200 meters from the trap, and still nearer the laccolith it is transformed into graphite.

Nine coal seams are found at three points of the region, but of these only the two located along the Norilsk River may be considered workable. The thickness of the upper seam ranges from 1.7 to 3.2 meters, and the lower seam from 2.3 to 6.6 meters; the average thickness of the two combined is 7.8 meters.

The actual, probable, and possible reserves of coal in the area explored are 22.2, 9.8, and 35.5 million tons respectively. Of these reserves, about 32 million tons can be worked by tunnels. The percentage of ash in the workable seams ranges from 5.5 per cent. to 12.6 per cent.; the calorific power (calculated according to Gutai's formula) varies in limits from 7,261 to 7,870 calories. The sulphur content was determined in a few specimens, ranging from 0.45 per cent. to 0.75 per cent. Thus, the coal of Norilsk may be considered an excellent fuel for ships; this has been confirmed by the assays made by the Vilkitski's hydrographical expedition in 1897.

Explorations of the Norilsk region have been made by order of the Siberian Section of the Russian Geological Committee in connection with the question of the establishment of the North Sea Route. Since steamboats sailing from European ports for the mouth of the Yenisei River must bring fuel for the return trip as well, 17 per cent. of their tonnage remains unavailable, and the possibility of their obtaining a

supply of fuel at the places of trans-shipment of their cargoes is a question of great importance.

Two coal deposits near the mouth of the Stony Tunguska River were examined by Mr. Obruchev in 1921. They consist of two seams, 2.8 and 5 meters thick, separated by a bed of quartz sands 11 meters thick. Analysis of the samples taken from the outcrops gives the following results: moisture, 12.05 per cent. to 20.05 per cent.; ash, 7.24 per cent. to 15 per cent.; volatile matter, 29.29 per cent. to 42.25 per cent. In view of the high percentage of moisture and the low calorific power (6,664–7,030 calor.), the coals are considered to be an intermediate coal between bituminous and brown. Though of low quality, the coal can be used as fuel for river steamers because of the situation near the Yenisei and favorable conditions for mining. The possible reserves are estimated to be 5,000,000 tons.

Four outcrops are found on the Kureika River, about 38 miles above its mouth. The coal is anthracite, containing 3.15 per cent. to 5.12 per cent. of volatile matter and 5.22 to 16.65 per cent. of ash. The seam is over 31 feet thick. The mining of this coal may be developed in connection with the probable exploitation of a large graphite deposit situated here, which due to its high quality—carbon from 82 to 96 per cent.—may be a good object for export. Also, since the Kureika River is navigable for almost the entire distance from its mouth to the coal and graphite deposits, they can be easily transported to the Yenisei River. The actual graphite reserves are estimated at 600,000 tons, possible over 3,600,000 tons.

There are a number of other graphite deposits. Especially noteworthy is the deposit on the Fatianikha River, about 60 miles above its mouth, which consists of several seams of graphite containing 90.69 per cent., 92.58 per cent. of carbon, and 6.1 per cent. to 6.9 per cent. of ash. One of the seams is over 5 meters thick. The actual reserves are estimated at 40,000 tons, the possible reserves over 3,220,000 tons.

P. P. GOUDKOFF.

57

SOCIETY OF ECONOMIC GEOLOGISTS

This department has been established for the official communications of the Society of Economic Geologists whereby the affairs of the Society such as notices, minutes, titles of papers, elections, etc., may be brought regularly to the attention of its members.

The Society announces that funds will be on hand again for the scholarship in Economic Geology for the collegiate year 1923–1924 as a result of funds received from the sale of Political and Commercial Geology.

In February, 1924, the Society of Economic Geologists will hold a joint meeting to discuss the report of the Secondary Enrichment Investigation in charge of L. C. Graton.

The May Meeting of the Society in New York promises to be well attended and to include a good geographic representation of the membership. Among some of the papers which have been promised to date are: Gold Quartz Veins of Cornucopia, Oregon, by J. F. Kemp and M. M. Dixon; Radio-active Minerals in Ontario, by Willet G. Miller; Some Notes on Ontario Gold Fields, by Cyril W. Knight; Recent Progress in Leached Croppings, by Augustus Locke and H. W. Morse; Some Notes on an Arizona Asbestos Deposit, by Alan M. Bateman; Salt Domes, by E. L. DeGolyer; Diamond Deposits of Portuguese West Africa, by C. M. Farnham; Occurrence of Ore Bodies at Britannia Mine, B. C., by S. J. Schofield; Fissility of Shale and Its Relation to Petroleum, by J. Volney Lewis; Application of Combined Geological and Electrical Prospecting, by A. Gravelin (Director of Swedish Geological Survey); Relation of Residual Manganese to Peneplains in Tennessee and Virginia, by D. F. Hewett; Geology of the Pearl Lake Gold Area, Porcupine, Ontario, by D. C. H. Wright; Kirkland Lake Gold Area, by P. E. Hopkins; Apex Gold Area, Herb Lake, Canada, by J. A. Reid.

Discussions will be initiated by Edward B. Mathews on Obtaining Release of Scientific Information from Commercial Companies, and by G. F. Loughlin on the Relation of Groundwater to Economic Geology.

The Presidential address will also be delivered.

SCIENTIFIC NOTES AND NEWS

Waldemar Lindgren, professor of economic geology at the Massachusetts Institute of Technology, has been appointed consulting engineer for the Eureka Smelting and Mining Company.

John A. Dresser was elected president of the Canadian Institute of Mining and Metallurgy at the Montreal meeting.

K. C. Heald is a the University of Chicago, from April 1 to June 12, delivering a course of lectures on petroleum geology, in the absence of W. E. Wrather.

J. D. Sears is acting chief of the Section of Petroleum Geology of the U. S. Geological Survey during the absence of K. C. Heald.

Frank W. DeWolf has resigned from the State Geological Survey of Illinois to become Chief Geologist of the Humphreys-Fohs oil interests, and will be at the Great Southern Life Building, Dallas, Texas.

A. W. Ambrose, assistant director of the U. S. Bureau of Mines, was recently made head of the Bureau's leasing branch and is visiting all the field offices having jurisdiction over leasing matters. He will also act as consulting engineer to all branches of the Bureau on matters relating to petroleum and natural gas.

H. H. Knox is in Rhodesia to examine the Cam and Motor property.

Verne L. Havens, has been made permanent secretary of the International Engineering Congress, composed of engineers of North America and the Latin-American republics.

F. L. Ransome was recent visitor at Lehigh University, where he delivered two lectures—one on the preparation for the career of an economic geologist, and the other on a sketch of the geology and ore deposits of Arizona.

Max W. Ball has been elected President of the American Association of Petroleum Geologists, and Frank DeWolf vice-president.

A. C. Spencer of the U. S. Geological Survey has been on leave without pay from April 6 to May 5.

Robert V. V. Anderson, director of the Whitehall Petroleum Co., of

London, has returned from the West Indies, where he has been carrying on oil investigations.

T. Wayland Vaughan, of the U. S. Geological Survey, on March 29 to 31 gave a series of five lectures on the origin of limestone and coral, coral reefs, and coral reef regions before the faculty and advanced students of the Department of Geology of the University of Wisconsin. He also lectured at the University of Iowa.

Pentti Eskola, who for the last eighteen months has been carrying on research work at the Geophysical Laboratory, Carnegie Institution of Washington, has returned to Finland to undertake work for the Geological Survey of that country.

H. A. C. Jenison left Washington in March to examine the Black Canyon and Boulder Canyon reservoir sites for the U. S. Geological Survey.

C. W. Purington has returned to Japan after paying a brief visit to this country.

W. C. Phalen, geologist for the Solvay interests, lectured before the faculty and students in the Geological Department of Syracuse University in March. The subject of the lecture was "The Marketing of Salt."

Malcolm Maclaren, of London, has been examining the Camp Bird mine at Ouray, Colorado.

L. D. Ricketts, of Warren, Arizona, has resigned as a member of the board of regents of the University of Arizona.

Francis Winslow, of the U. S. Bureau of Mines, has been assigned to serve with the War Minerals Relief Commission as its chief engineer.

Robert Peele, editor of the Mining Engineers' Handbook, has been awarded the gold medal of the Mining and Metallurgical Society of America.

F. W. McNair, president of the Michigan College of Mines at Houghton, attended a meeting of the Board of Visitors of the Bureau of Standards in March. Dr. McNair was recently appointed to this board by Herbert Hoover.

F. B. Weeks, formerly geologist for the U. S. Smelting, Refining, and Mining Company, has opened an office in San Francisco.

Colin Fraser has been elected president for 1923 of the Australasian Institute of Mining and Metallurgy.

John Hays Hammond has endowed a scholarship in engineering for a Mexican student at Yale University, to cover transportation and all expenses of a four years' course.

Arthur Eaton has opened an office in the Merchants Exchange Building, San Francisco.

H. K. Linn left New York in March for the Belgian Congo, where he will be identified with interests engaged in diamond mining.

William H. Haas, associate professor of geology in Northwestern University, has returned after a trip of nine months in South Amercia, where he was investigating mineral deposits.

R. A. Farquharson, of the West Australian Geological Survey, has been appointed geologist for the British Somaliland Protectorate.

Per Geijer and L. L. Fermor have been elected to the Board of Associate Editors of the journal, ECONOMIC GEOLOGY.

The American Association of Petroleum Geologists held its eighth annual meeting in Shreveport, Louisiana, from March 22 to 24. The meeting was well attended by geologists from all parts of the country, and an interesting program was prepared. The first day was devoted to the southern fields, 21 papers being presented on the Coastal Plain Region of Alabama, Arkansas, Louisiana, and Mississippi, and on the Texas fields. The following day Mexico and the Midcontinent were discussed, and 23 papers were given. The 21 papers of the last day took up a discussion of salt domes and other more general subjects.

The U. S. Geological Survey is giving an examination for Editorial Assistants of May 23, at entrance salaries ranging from $1800 to $2400 a year. The duties of the position are to prepare for printing and to criticize and correct manuscripts dealing with geology in all its branches, mineral production, and water resources, and to read and correct proof sheets. Full information and application blanks may be obtained from the United States Civil Service Commission, Washington, D. C.

KANSAS STATE AGRICULTURAL COLLEGE
MAY 14 1922
LIBRARY